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THE ELEMENTS OF CLOCK and WATCH-WORK,

Adapted to PRACTICE.

In TWO ESSAYS.

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G.R. III.
BRITISH MUSEUM

TO THE

KING.

SIR,

YOUR MAJESTY's approbation of my former endeavours for improvement in the art which I profeſs, induced me to compoſe theſe Eſſays; and as Your bounty has afforded me the leiſure to purſue my reſearches, nothing could give me greater happineſs, than the permiſſion of thus laying them at Your MAJESTY's feet.

IT is almoſt the peculiar glory of Your MAJESTY's reign, that the peace which the ſucceſs of Your MAJESTY's arms preſcribed to Europe, and the wiſdom of Your councils planned for Your people, is adorned by Your MAJESTY's MUNIFICENT PATRONAGE of all the Arts, uſeful as well as ornamental. The ſubject of the following pages partakes of both: and their author humbly hopes that they tend to public utility; the only return which Your MAJESTY requires, and the only retribution he can make for Your Royal bounty.

HE begs leave to aſſure Your MAJESTY, that he ſhall ever be impreſſed with the deepeſt ſenſe of Your MAJESTY's exalted virtues, as well as with the deepeſt gratitude for the favours Your MAJESTY has been moſt graciouſly pleaſed to extend to him, and that they ſhall be employed in his hourly endeavours to deſerve them.

WITH

DEDICATION.

WITH the moſt profound veneration, he preſumes to ſubſcribe himſelf,

May it pleaſe Your MAJESTY,

Your MAJESTY's Moſt Faithful,

Dutiful, and Devoted

Subject and Servant,

LONDON,
Feb. 26th, 1766.

ALEXANDER CUMMING.

TO THE

READER.

THE very favourable opinion which the Author of the following Eſſays entertains, and (notwithſtanding all malicious reports to the contrary) always has entertained, of the great natural abilities of Mr. JOHN HARRISON, induced him to delay this publication, till Mr. HARRISON had received the reward of his long and unwearied application, by diſcovering the reſult of his labours. That diſcovery being now made, the public from thence will judge of the merits of his improvements; and poſſibly from a compariſon between them and the following Theory, the Reader may be enabled to decide, how far the calumny, ſo groundleſsly conceived, and ſo artfully propagated againſt me, was well founded. Should any further vindication be neceſſary, I am ready, if called on by my accuſers, publicly to declare the reaſons for ſuch part of my former conduct, as has ſo much diſpleaſed them, and obviate any objections to the following performance, if fairly and candidly urged: but no regard will be paid to any anonymous opponent, in a controverſy that has truth alone for its object.

AN
ESSAY
TOWARDS THE
Improvement of CLOCK-WORK.

GENERAL PLAN.

Clocks go better than Watches.

1. *IT is univerſally allowed, that the moſt ordinary Clock with a royal Pendulum, meaſures Time better than any Watch, conſtrued in the manner hitherto practiſed.* And,

Watches as well executed as Clocks.

2. *That Watches are, in general, as well executed as Clocks.* From which it is evident,

Clocks derive their ſuperiority from principle.

3. *That Clocks derive their ſuperiority from principle: and that a due attention to their natural properties, may at leaſt, be the means of improving Watch-work.*

Clock-work into two general Heads.

4. The Theory of Clock-work naturally divides itſelf into the two following general Heads, viz.

First.

5. *What pendulous Vibrations have their Iſochroniſm leaſt influenced by equal cauſes?* And,

Second.

6. *What conſtruction of a Clock will leaſt alter the Iſochroniſm of the ſame Pendulum?*

CLASSES.

7. All Clocks may be reduced to two Claſſes; namely, ORDINARY and ACCURATE.

In ordinary Clocks particular regard to expence and ſimplicity.

8. In ORDINARY Clocks, ſuch as are generally uſed for domeſtic purpoſes, particular regard ſhould be had to their ſimplicity and expence.

In the more accurate, no expence ſhould be ſpared.

9. In Clocks that are intended for aſtronomical and other *very accurate* Obſervations, no expences ſhould be ſpared, while the performance can be further improved. *I ſhall therefore enquire,*

Firſt enquiry.

10. In the firſt place, *How far the performance of Clocks may be improved, without much increaſing their expence.*

Second.

11. And in the ſecond, *What is the utmoſt degree of perfection, of which they ſeem ſuſceptible.*

Pendulum only has a natural tendency to meaſure the Time.

12. Since a Pendulum is the only part of a Clock that has a natural tendency to meaſure Time, I ſhall here mention its known properties in its *ſimple ſtate*, detached from Clocks, and deſcribing circular Arc's.

Its natural Properties in a detached ſtate.

13. Firſt, *A Pendulum once put in motion, would ever continue to vibrate equal Arc's, if no external cauſe did tend to deſtroy its motion.* And,

Of PENDULOUS VIBRATIONS.

14. Second, *All thoſe equal Vibrations would be performed in equal times.*

15. Third, *The momentum of Pendulums is as the verſed ſine of their angle of Vibration into their quantity of matter.*

16. Fourth, *Pendulums of equal length, though unequal weight, will* (cæteris paribus) *perform their Vibrations in equal times.*

17. Fifth, *All Pendulums alter their time of Vibration in different latitudes. And their times of aſcent and deſcent are equally influenced.*

18. Sixth, *A Pendulum cannot reſt but when its centre of gravity is directly below its point of ſuſpenſion.*

19. Seventh, *The ſhorter Vibrations in circular Arc's are performed in leſs time than the longer**.

Demonſtrated chiefly by Mr. Hugens.

20. The foregoing properties are chiefly demonſtrated by Mr. HUGENS in his HOROLOGIUM OSCILLATORIUM, and tranſlated into Engliſh in KEIL's Introduction to Natural Philoſophy, and a ſtrict attention to them ſeems abſolutely neceſſary to the improvement of Clock-work.

Motion loſt.

21. If a pendulous body be made to vibrate in a reſiſting medium, (as air,) each Vibration

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* Mr. HUGENS has demonſtrated, that 29 ſemicircular Vibrations take as much time as 34 of the ſhorteſt Vibrations of the ſame Pendulum, independent of the influence of the Air.

Of pendulous Vibrations.

will, by means of ſuch reſiſtance, become ſhorter than the preceding one, till at laſt the Pendulum comes to reſt; hence (19) thoſe Vibrations *will not* be performed in equal times.

How they may be rendered iſochronal.

22. But if the reſiſtances of the medium, &c. were *uniformly the ſame*, and a power could be applied that would communicate to the Pendulum at each Vibration as much motion as thoſe reſiſtances deſtroy; then would all the Vibrations be *of equal length*, and performed *in equal times*.

Enquiry.

23. But as neither the reſiſtances that tend to deſtroy the motion, or the power that maintains the Vibrations of Clock-Pendulums, are perfectly uniform; I proceed to enquire

Whether long or ſhort ones are moſt influenced.

24. *Whether long or ſhort Vibrations have their Iſochroniſm leaſt influenced by thoſe irregularities*.

Princ. Math. Prop. 28. Coroll. 2.

25. Sir Isaac Newton has demonſtrated; "That a *Funipendulous Body* "vibrating in a "reſiſting medium, would have its ſhort Vi-"brations more iſochronal than its longer;" That is, *in other words*; that the longer Vibrations being more reſiſted than the ſhorter ones, do ſooner alter their lengths, and conſequently (19) their times of Vibrations. But

26. Let a power be any how applied that will communicate as much motion to the Pendulum as the reſiſtances of the medium, &c.

do deſtroy; then will the Vibrations continue equal and iſochronal.

Of PENDULOUS VIBRATIONS.

Total reſiſtance of the Air not to be regarded.

27. Thus, we are not to conſider *the total reſiſtances of the air*, *friction*, &c. ſince *a power* can be eaſily applied that will ballance them, ſo long as they continue uniform. *And this power, from whatever cauſe*; *I call the* MAINTAINING POWER.

28. But we are to enquire, what influence *any Change*, in the reſiſtance, or in the maintaining power, would have on Pendulums of equal weight, but deſcribing unequal Arc's.

PLATE I. FIG. I.

Comparative advantage of long and ſhort Arc's.

29. Let any power be applied to the pendulous body B, capable of moving it from its place of reſt, to M or G; join M G, and draw O N parallel to the line M G, and let M O, the *perpendicular height* to which it is raiſed, be divided into any number of equal parts, ſuppoſe five; through the extremity of each part, draw a ſtraight line parallel to M G, till they meet the Arc in the points L, K, I, H, and if the power that raiſes the body B to M, be alſo divided into five equal parts, one of thoſe parts will raiſe B to H; two parts will raiſe it to I; three parts will move it to K; four parts to L, &c.

Equal powers give unequal ſpaces, but agree in height.

30. Here it is to be obſerved, that though the power be applied by equal portions, the ſpaces deſcribed are unequal; but agree *in perpendicular height* with the power applied.

31. Let

Of PENDULOUS VIBRATIONS.

PLATE I. FIG. I.

Conſtruction of the Figure.

31. Let the Arc B G, be divided into five equal parts by the points C, D, E and F, through which points draw ſtraight lines parallel to M G, till they meet A B and G N; then will the line **G N** repreſent the power neceſſary to raiſe the body B, to the point G; *and its parts*; the powers neceſſary to raiſe it, to *their* correſponding points in the Arc*.

Increaſe in height as the power, and decreaſe as the reſiſtance.

32. Now ſince the increaſe of perpendicular height is as the increaſe of power applied (30), it follows that the decreaſe in perpendicular height, will be as the increaſe of reſiſtance; or as the diminution of power: *Therefore,*

Illuſtration.

33. Let there be any number of Clocks, *ſuppoſe five,* whoſe Pendulums are *exactly equal,* but whoſe angles of Vibration are to each other, as 1, 2, 3, 4 and 5; or let the bodies C, D, E, F and G, repreſent their relative Pendulums at the extremity of their Vibrations.

Experiment.

34. If thoſe five Clocks be expoſed to the ſame degree of cold, their oil will be equally influenced, and by that means, *their maintaining powers equally diminiſhed:* And conſequently, there will happen an equal diminution in the

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* It is evident, G N is divided into a ſcale of verſed ſines; therefore if gravity alone oppoſed the aſcent of the Pendulum, the powers neceſſary to raiſe it to any of the poſitions, C, D, E, F, G, would be as the relative verſed Sine of thoſe Arc's; as would alſo the momentum of the Pendulum in deſcending from any of thoſe points.

perpendicular height of the Vibrations of each Pendulum (32).

35. Let thoſe Clocks continue expoſed to the cold, till ſome one of them is deprived of all its motion; it is required, Which Pendulum will firſt come to reſt? *and in what degree the others are influenced?*

Shorteſt Vibration ſooneſt comes to reſt.

36. Since all the Pendulums are equal (33), it is obvious that the one which deſcribed the ſhorteſt Arc, will ſooneſt come to reſt (15).

37. But the Pendulum C has (36) loſt all its motion, and conſequently its perpendicular aſcent: *Therefore*, (32, 34,) deduce from the height of the other Pendulums D, E, F and G, each, a ſpace equal to the greateſt height of C; as repreſented on the ſcale G N; through thoſe points, draw lines parallel to G M till they meet the Arc B G, on which, they will ſhow the diminution in the length of Vibration in each Pendulum; *as repreſented in the figure, by dotted lines.* Or

38. Deduce the verſed ſine of the angle deſcribed by the Pendulum C, from each of the verſed ſines of the angles deſcribed by the Pendulums D, E, F, and G, at beginning of all their Vibrations; and the remainders will be the verſed Sines of each reſpective Vibration, when the Pendulum C has loſt all its motion.

39. From which it plainly appears, *That in Clock Pendulums, equal cauſes do moſt alter the lengths of the ſhorteſt Vibrations.*

Of PENDULOUS VIBRATIONS.

PLATE I. FIG. I.

40. It is further to be obſerved, that although the ſame cauſes did ſhorten the Arcs of Vibration *of all* thoſe Pendulums *equally*, the effect it would have on their times, would be, as the change produced in each Vibration, to *the whole length of Vibration* (14).

Comparative advantages in duplicate proportion of the Arc's.

41. But equal cauſes produce leſs alteration in the length of long Vibrations, than it does in ſhort ones (39). Therefore (40), *the comparative advantages of different Vibrations in Clock Pendulums are* (cæt. par.) *in the duplicate proportion of their relative length.* Which may otherwiſe be illuſtrated; thus,

PLATE I. FIG. 2. Another illuſtration.

42. Let any body E, vibrate in the circular Arc A C E, I ſay that the advantages of its longer Vibrations are to that of its ſhorter ones, in the *duplicate proportion* of the length of thoſe Arc's.

Conſtruction of the Fig.

43. For, join A E, and from C, the loweſt point of the Arc, draw a line perpendicular to A E; which perpendicular divide into four equal parts, and through their extremities draw ſtraight lines parallel to A E, till they are terminated by the Arc; join E C, and parallel to it, draw a line touching the Arc in D; then E D will be equal to D C, and conſequently E C will be double of D C. *Now*

Demonſtration.

44. Let two equal bodies E and D deſcribe the Arc's E C, and D C; it is evident (32), that four times as much reſiſtance will be re-

quired to bring E to reſt, as will deſtroy the motion of D; in the ſame manner is proved, that four times as much reſiſtance is neceſſary to deſtroy the motion from D to C, as from h to C.

Equally true of the proportional parts as the whole.

45. What is above ſaid of whole Arc's, is equally true of their proportional parts; for, if the whole reſiſtance, neceſſary to deſtroy the motion of any body, deſcribing a circular Arc, be divided into ſixteen equal parts, it will require twelve of thoſe parts to reduce the Vibration to half the length; three more parts will reduce it to a fourth of the whole length; and if the remaining Sixteenth of the momentum be again divided as above, the ſame proportion will hold, till the Arc entirely vaniſhes.

The reſiſtances that produce proportional alterations, are as thoſe that deſtroy the whole motion.

46. Therefore (by the 12th Prop. Book Fifth Euc.) the reſiſtance neceſſary to produce proportional effects in the Iſochroniſm of Vibrations of different lengths (41), will be to each other *c p*, as the reſiſtance that deſtroys their whole motion, i. e. (32) as their relative verſed ſines: *And therefore*,

Concluſion in favour of long Vibrations.

47. In Clocks, *the advantages of long Vibrations, are univerſally in the duplicate ratio of the Arc's deſcribed.*

48. But leſt it ſhould be objected, that the power neceſſary to maintain Vibrations of different lengths, will be in the duplicate ratio of their reſpective Arc's; and that the friction on

the movement will increaſe as the power; and conſequently, that the power neceſſary to maintain the motion in Clocks, will bear a greater proportion to the momentum of the Pendulum, in long Vibrations than in ſhort ones; *it is neceſſary to obſerve*; *that*,

49. Though the whole friction increaſes as the weight, or power applied to a Clock, it does not follow, that the changes, or accidental variations in it obſerve the ſame law (27).

Further conſideration.

50. The *natural* friction * continues uniformly the ſame while the preſſure on the rubbing ſurfaces is uniform; and if any certain quantity of the maintaining power be conſtantly deſtroyed by friction, it can no way affect the Iſochroniſm of the Pendulum; for what could be more abſurd than allowing for the influence of any power, *where* it *never reaches*.

51. Since any increaſe in the maintaining power, will have the ſame effect on the Pendulum as a diminution in the reſiſtance of the Air; and *vice verſa* (32); It follows that,

What has been ſaid of reſiſtance is applicable to the maintaining power.

52. What has been ſaid concerning the reſiſtance of the medium, &c. is equally applicable to the changes of the maintaining power (32, 41, 47).

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* I do not here mean to aſſert, that there are not exceptions to what is ſaid of the uniformity of natural friction; but as ſuch exceptions do not invalidate what is here ſaid, they are reſerved for another place.

Changes only in the maintaining power to be regarded.

53. I formerly obſerved, (27, 28,) that the *changes only* that happen in the reſiſtance of the medium, &c. to Clock Pendulums, are to be regarded; the ſame is true concerning the action of the Wheels on the Pendulum (50).

Action of the Wheels.

54. As to the irregularity of action in Wheelwork; their fluctuations are conſtant and *periodical*, and in the action of each Tooth, correct themſelves; ſo that, if the effect does not become perceptible during the action of any one Tooth of a Wheel, it will not, in any number of revolutions; for the error does not accumulate.

Fluidity of the oil, &c.

55. The changes that happen in the maintaining power from the different ſtates of fluidity in the oil, are of a contrary nature; for the times of their duration, and returns, and conſequently the errors ariſing therefrom, are *uncertain*, as depending upon external cauſes; and they accumulate, as ſhall be ſhewn hereafter.

As to the Time of going without winding.

Does not matter ſo much in Clocks as in Watches.

56. It is only to be regarded ſo far as it tends to render the machine more or leſs complicated; for, *in Clocks*, we have power at command, and may have any degree of influence at pleaſure on

the pallets, without regard to the continuation of the Clock's going: *Thus,*

Theory.

57. *In theory*, if a weight of two pounds be neceſſary to maintain a Vibration of any given length, *ſuppoſe one degree*, for eight days; a weight of eight pounds will maintain the ſame for thirty-two days (one month); and a weight of one hundred and four pounds will maintain it for a year; ſuppoſing the perpendicular deſcent of the weight the ſame in each caſe.

58. Now let us enquire which of thoſe three caſes is moſt advantageous for practice.

Friction greateſt in thoſe Clocks that go longeſt.

59. By ſuppoſition (57) the influence, or action of the Wheels on the pallets, is equal in each caſe; the Vibrations are equal (57) alſo; therefore the friction on the pallets, as alſo on all the correſpondent parts of each Clock, will be equal; but the month Clock has one Wheel, and the year Clock two Wheels, more than the week Clock; and each Wheel has its friction; conſequently the friction is greater in the month Clock than in the weekly one, and ſtill greater in the annual Clock than either: *But*

Not hurtful to the performance if it remains uniform.

60. If the friction remains uniform, an additional power may be applied that will render the action on the pallets equal in each Clock; in which caſe, the Pendulums *(cæteris paribus)* would vibrate in equal times; nor would their Iſochroniſm be any how influenced by the above *uniform* difference in friction (50).

61. But

TIME OF GOING.

Influences of the Oil.

61. But the influences of heat and cold on the oil applied, will tend to vary the action of the Wheels on the pallets, and conſequently the length of Vibration (52) and Iſochroniſm of the Pendulum (19).

Moſt hurtful in thoſe Clocks that go longeſt.

62. And, as this influence may reaſonably be ſuppoſed equal, on the correſponding parts of thoſe Clocks; the additional Wheels muſt have their additional influence; and the Iſochroniſm of the Pendulum is more diſturbed in an annual, than a monthly Clock; and in it, than a weekly one (55).

Why 24 hour Clocks are not uſed.

63. It may poſſibly be ſaid, that for the ſame reaſon, a 24 hour Clock ſhould go better than an eight-day one; but the inconveniencies attending the uſe of the former might more than ballance its advantages.

Clocks ſtand in time of winding up.

64. If any ſhould ſay, that Clocks in general either ſtand, or have a retrograde motion in time of winding, and that this error is leaſt in Clocks of long continuation; I anſwer, that every good mechanic knows how to remedy this imperfection: But this I paſs, as foreign to my purpoſe.

Eight-day Clocks beſt.

65. *From the above conſiderations it appears, that for an accurate meaſure of time, eight-day Clocks are preferable to thoſe of a longer continuation.*

Weight of the Pendulum.

Velocity as the motive force.

66. Since the velocity generated is cp as the motive force impreſſed: *it follows*,

Times inverſely.

67. That the times of Vibration of a Pendulum will always be inverſely as the motive force *.

In detached Pendulums, gravity only the motive force.

68. In Pendulums *detached from Clocks*, the action of gravity *only*, is the motive force: *Hence*,

All Pendulums of equal length, iſochronal, &c.

69. The Vibrations of all Pendulums of *equal length*, and deſcribing *equal Arc's*, are iſochronal in the ſame latitude †.

Not ſo in Clocks.

70. But when a Pendulum is applied to a Clock, the *Impetus of the Wheels*, together with *the action of gravity*, conſtitute the motive force.

Alteration in the action of the Wheels, deſtroys the Iſochroniſm.

71. *Hence*, any alteration in the action of the Wheels on the Pendulum, will alter the time of Vibration (67).

Proportion of ſuch alteration in time.

72. And the alteration that will happen in the times of Vibration of a Clock, will always be to the whole time of its Vibrations, nearly as the

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* The Vibrations are here ſuppoſed of the ſame length; or that all the parts that conſtitute the motive force, do act during the whole time thereof.

† For the action of gravity, and the *Vis Inertiæ* will bear the ſame proportion to each other, whatever be the quantity of matter.

alteration

WEIGHT OF THE PENDULUM.

alteration in the motive force, to the whole motive force (66, 70).

Heavy Pendulums leaſt influenced.

73. Thus, it is obvious, that *(cæt. par.)* the heavier the Pendulum, the leſs proportion will any alteration that may happen in the action of the wheels bear to its whole motive force (70), *and conſequently*, the ſmaller the alteration in the times of its Vibration (72)*.

Illuſtration.

74. *To illuſtrate this farther*, let us ſuppoſe the action of the Wheels *equal* to *the action of gravity* on the Pendulum, and let this action of the Wheels be ſo applied, that it *oppoſe the aſcent* and *promote the deſcent* in the very ſame manner that gravity does: then, will the times of Vibration be only half as long as they would, if gravity alone acted; *for the velocity will be doubled* (66), *and the length of Vibration remain the ſame.*

Ditto.

75. And if by any means the action of the Wheels on the Pendulum be diminiſhed, ſuppoſe $\frac{1}{30}$ the motive force of the Pendulum will (70, 74,) be diminiſhed $\frac{1}{60}$, which will alſo diminiſh the velocity in the ſame proportion.

Ditto.

76. But if the weight of the Pendulum be double the action of the Wheels, and their action as formerly, be diminiſhed $\frac{1}{30}$, it will only

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* Becauſe the action of gravity on the Pendulum is unalterably the ſame, in the ſame place.

Weight of the Pendulum.

make a difference of $\frac{1}{90}$ in the velocity; and conſequently in the time (67).

Ditto.

77. Let the weight of the Pendulum be quadruple the action of the Wheels, then will an alteration of $\frac{1}{30}$ of the action of the Wheels make only an alteration of $\frac{1}{150}$ of the motive force (70); and conſequently in the velocity and times.

Ditto.

78. Let the action of gravity be to the impetus of the Wheels on the Pendulum, as 100 to 1; then if the action of the Wheels as formerly be repreſented by 30, the *whole motive force* of the Pendulum will be 3030, and a diminution of $\frac{1}{30}$ in the action of the Wheels, will make an alteration of $\frac{1}{3030}$, in the motive ſorce and velocity of the Pendulum: Hence a Clock would loſe, one minute in 3030.

Application.

79. Thus it appears, that *the ſame cauſe* that produces an alteration of *one minute per hour*, with a Pendulum whoſe weight is equal to the action of the Wheels (74), * will only cauſe an alteration of a minute in an *hour and half*, when the weight of the Pendulum is double the action of the Wheels (76); *a minute in two hours and a half*, when the weight of the Pendulum is quadruple the action of the Wheels (77); and an alteration of one minute in 3030, *(two days,*

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* That is, a Pendulum, on which the influences of the maintaining power and gravity, are equal: or in which each of them contribute equally to its motive force.

two hours, and 30 *minutes*), when the weight of the Pendulum is to the action of the Wheels, as 100 to 1 (78).

WEIGHT OF THE PENDULUM.

Alteration in the whole time: as, &c.

80. Hence it is evident, that *the alteration in the meaſure of time*, is (cæt. par.) *to the whole time*, as *the alteration of the motive force of the Pendulum* (70) to *its whole motive force.*

Advantage of Pendulums, &c.

81. And therefore, the advantages of Pendulums, are *(cæt. par.)* as their weight *.

82. I have here conſidered the action of the Wheels, as oppoſing the whole aſcent, as well as accelerating the deſcent: in which caſe, any alteration in it, (commencing at the extremity of Vibration) would have the ſame effect with an alteration in the power of gravity; that is, it would alter the velocity and times, without altering the Arc of Vibration.

Why the Arc's are increaſed and diminiſhed.

83. But *in all Clocks*; the action of the Wheels, muſt promote the deſcent, more than it oppoſes the aſcent of the Pendulums (or the contrary,) and conſequently, the Arc of Vibration will be increaſed or diminiſhed with the action of the Wheels: and the times of Vibration rendered more iſochronal than above ſtated (79); but the relative proportions of the changes that will happen in the times, will nearly remain the ſame.

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* Though I have here ſtated the advantage of heavy Pendulums as unlimited, I ſhall hereafter endeavour to ſhew, why the practice may not, beyond certain limits, agree with the theory.

MOMENTUM OF THE PENDULUM.

ſame *. *I now proceed to compare, the* MOMENTA OF PENDULUMS, differently acquired.

84. I have in a former part of this Eſſay ſhewn, *that the advantages of long Vibrations, bear a duplicate proportion to their Arc's* (41, 47).

85. Therefore, if there be two Pendulums, of equal weight and deſcribing equal Arc's, and it be required to increaſe the momentum in each equally; but in the one by weight, and in the other by increaſing the Vibration, it may be done as follows:

Table of the momenta deſcribed.

86. Suppoſe each Pendulum ſix pound weight, and to vibrate one degree from its point of reſt, then will their momentum and advantages be equal; but if their momenta be equally increaſed (85), as above, the weight of the one, and the angle of Vibration of the other, muſt be, *as in the following table*; where you have in the firſt column, the increaſe of momentum, and directly oppoſite to it, the weight of *the one Pendulum* in pounds, and the angle of Vibration of *the other*, in degrees and minutes.

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* The height to which a Pendulum will riſe, depends on its velocity at its loweſt point; without any regard to the means by which ſuch velocity was acquired: Hence, though the action of the Wheels on the pallets, accelerates the deſcent, it in ſome meaſure corrects ſuch acceleration in circular Arc's, by enlarging the following Vibration (19). But this does not happen in cycloidal Arc's.

87. This

MOMENTUM OF THE PENDULUM.

Momentum.	Weight in libs.	Angle of Vibration in deg. and min.	
1	6	1	
2	12	1	25
3	18	1	44
4	24	2	
5	30	2	15
6	36	2	27
7	42	2	39
8	48	2	50
9	54	3	
10	60	3	10
20	120	4	28
40	240	6	19
80	480	8	57
100	600	10	1

87. This table alſo gives the momentum of the ſame, or equal Pendulums, vibrating different angles. *Thus:*

Further uſes.

88. Find the angles of Vibration in the laſt column, and oppoſite to them in the firſt, you have the momenta. *Ex.* If the one vibrates *one degree*, and the other *ten degrees*, their momenta will nearly be, as *one hundred to one:* If the one vibrates two degrees fifteen minutes, and the other eight degrees fifty-ſeven minutes, their relative momenta will be, as *five* to *eighty*; and their advantages in correcting the irregularities of the movement, are as the relative momenta (47, and 81,) that is, directly as the weight, and in the duplicate ratio of the Arc.

Ditto.

Example.

89. *But to come cloſer to the purpoſe*; let us ſuppoſe that there be given a Pendulum of eight pound weight, deſcribing an Arc of *ten degrees from the loweſt point*; if it be required to make a Pendulum that ſhall have equal momentum with the former, and only vibrate *thirty minutes from its loweſt point*, its weight in round numbers muſt be 3000 pounds; a weight, that I am apt to think, the greateſt admirer of ſhort Vibrations would not, without apprehenſions,

apply to a Houſe-clock: but *there appears not the leaſt riſque or inconveniency in acquiring the ſame momentum, by enlarging the Vibration as above.*

Objection to long Vibrations, and its anſwer.

90. It may be further urged in favour of ſhort Vibrations, that the influence of the oil on the pivots of the verge, is diminiſhed as the angle of Vibration. But is it poſſible to imagine! that any perſon ſhould think of this, without having firſt attempted to diminiſh the influence of the oil *on the pallets*; where the effect is at leaſt two hundred times as great?

Further illuſtration in the following parts, &c.

91. Thoſe who are not yet ſatisfied of the advantages of long Vibrations, may have further ſatisfaction, when the influences of the oil on the pallets and the reſiſtance of the air are conſidered. *And*

Query.

92. As ſome may enquire, what could have induced ſo many learned, and ingenious men, *to prefer ſhort Vibrations to long?* I ſhall endeavour to point out ſuch arguments, as appear of greateſt weight in ſupport of ſhort Vibrations.

Argument firſt, in favour of ſhort Vibrations.

93. *Firſt*, Becauſe ſhort Arc's of a circle, deviate little from the cycloidal curve: *They are ſuppoſed to partake of the ſame properties.*

Argument ſecond.

94. *Secondly*, Becauſe ſhort Vibrations are leſs liable to communicate motion to the point of ſuſpenſion. And

Argument third.

95. *Thirdly*, Becauſe they meet with leſs reſiſtance from the air, *and conſequently* are maintained by a ſmaller power; they are thought preferable to long ones. *But*

SHORT VIBRATIONS EXAMINED.

But let us now enquire, whether theſe are real or imaginary advantages.

Cycloidal properties.

96. And firſt, of the *cycloidal properties*, they ſeemingly having introduced ſhort Vibrations; I here confine my remarks to the eſtabliſhed theory only, and paſs all the imperfections of materials or execution.

By whom applied to Clocks.

97. Mr. HUGENS demonſtrated, that a Pendulum, vibrating in the cycloidal curve, would perform all its Vibrations, whether long or ſhort, in equal times [*]; and directly thought of applying this to Clock-pendulums, and pointed out a method, by which the center of oſcillation of a Pendulum might be made to deſcribe a cycloid.

Center of oſcillation, not a fixed point in cycloidal Vibrations.

98. *But here*, the center of oſcillation was conſidered as *a fixed point*; which cannot be in a Pendulum vibrating between cycloidal cheeks; for the Pendulum alters its length in every part of the Vibration, and conſequently the center of oſcillation muſt be continually changing its place, and ſo deſcribe a curve different from the cycloid; nor has any method been yet propoſed for obviating this difficulty.

Other objections to cycloidal cheeks &c.

99. But, *ſuppoſing this objection removed*, what is demonſtrated of Pendulums deſcribing a cycloid, is by no means true, after ſuch Pendulum is applied to a Clock.

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[*] But this demonſtration does not include the influences of the medium.

100. Sir

Sir Isaac Newton aware of this.

100. Sir Isaac Newton was well aware of Mr. Hugens's overſight in both theſe articles; for, when HE ſhews how to make a Pendulum deſcribe a cycloid, he ſuppoſes it a *point*. See his Prin. Math. Prop. 50.

101. And when HE demonſtrates the cycloidal properties of a Pendulum, (Prop. 51.) he expreſsly ſays, "THAT GRAVITY ALONE, ſhall act on the Pendulum;" which tacitly ſuggeſts, that when the Wheels of a Clock act on the Pendulum, the cycloidal properties are deſtroyed.

Argument in favour of cycloidal Vibrations.

Suppoſition not true.

102. But it may be ſaid, that if the Wheels of a Clock are made to act on the Pendulum, *in the very ſame manner that gravity does*, the cycloidal properties may be preſerved: but this ſuppoſes the action of the Wheels, as invariable as the action of gravity, which I imagine is not the caſe in any Clock, *that has yet been made*; and if any alteration happen in the action of the Wheels, thus applied; it will have *the ſame effect* on the meaſure of time, as *an alteration in the power of gravity.*

Action of the Wheels can never coincide in every reſpect with gravity on the Pendudulum.

103. Nor is it poſſible to make the action of the Wheels, *in every reſpect*, to coincide and cooperate, with gravity; *for* gravity promotes the deſcent in every point, and in the ſame manner oppoſes the aſcent; which can never happen in the action of the Wheels on the Pendulum; *for*,

Reaſon.

104. Though *it* may promote the deſcent, in the very ſame manner that gravity does, it can never

Of ſhort Vibrations.

never oppoſe the aſcent, *as much*, and *in the ſame manner*; for in that caſe, it would counter-act itſelf, and *ceaſe to maintain the Vibrations*: but of this more hereafter.

Enquiry.

105. Let us for a few minutes diveſt ourſelves of cycloidal prejudices, and found our enquiries on common ſenſe, and the following conſiderations will naturally preſent themſelves.

Cycloidal Vibrations hurt the performance with recoiling pallets.

106. Whenever cycloidal cheeks are applied, it is ſuppoſed that the longer Vibrations are ſlower than the ſhorter ones; but though this is the caſe in detached Pendulums, it is quite otherwiſe in thoſe applied to Clocks with recoiling pallets. For,

An eaſy experiment on recoiling clocks.

107. If we add, to the moving power of a Clock on the recoiling principle, its Vibrations will become longer, and at the ſame time quicker: this is a truth of which few, if any Clock-makers, are ignorant, and of which any perſon in poſſeſſion of a Clock of the recoiling principle, may ſoon be convinced *.

108. How

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* It may poſſibly be here ſaid, that though this has been generally if not univerſally the caſe, yet a certain mode and quantity of recoil, may be eſtabliſhed, that will give in practice, all the properties that the cycloid does in theory: but I am apt to think that ſuch inveſtigation, is much more difficult than that of the cycloid; and that the application of ſuch theory to practice, muſt be more critical than even that of the cycloid. For, admitting that the mode and quantity of recoil is inveſtigated, the application to practice, will be more difficult than the cycloidal cheeks, in proportion, as the face of the pallets is ſhorter

Of short Vibrations.

108. How abſurd then would it be, to render *thoſe quickeſt Vibrations*, *yet quicker*, by the application of cycloidal cheeks?

Further arguments againſt cycloidal Vibrations and a recoil.

109. *If thus*, *it appears*, that the application of the cycloid to Clocks, does even in *theory* increaſe the evil: What muſt they do? when we add, the *imperfections of execution*, the *elaſticity of cycloidal cheeks*, together with *the many changes that happen therein* by heat and cold, *and the bad effects that may ariſe from the corroſion of the metals*, *&c. &c* *.

Effect with a dead-beat poſtponed, &c.

110. I cannot here inveſtigate the effect of cycloidal cheeks with the dead-beat, without anticipating the theory of pallets, but ſhall hereafter endeavour to ſhew the impropriety of any application of them, ſince the effect of the denſity of the air, on the *motive force* of the Pendulum, does exactly balance the effects of its reſiſtance in circular Arc's: ſo far as they influence the meaſure of time, as ſhall be ſhewn in its proper place. *But here*

ſhorter than ſuch cheeks: and I ſhall ſhew hereafter, that in Clocks where the maintaining power is uniform, circular Vibrations are preferable to cycloidal ones; and the ſame objections ſtand in the way of any recoil of whatever kind.

* This chiefly alludes to ſuch Clocks as have a recoil, which has been the caſe with moſt, to which cycloidal cheeks have been applied; and in all Mr. Hugens's Clocks : but I ſhall ſhew in its proper place, that the cycloidal Vibrations are inferior to the circular, in a reſiſting medium whoſe denſity is changeable, whatever be the conſtruction of pallets.

Of SHORT VIBRATIONS.

111. It ſeems no more than reaſonable to conclude; *that ſhort Vibrations derive no greater advantages from any affinity they may be ſuppoſed to have to the cycloid*; *than the cycloid poſſeſſes.*

Impropriety of ſuppoſing that ſhort Arcs, &c.

112. And though all that hath been demonſtrated of the cycloid, had been as unexceptionable in *Clock-pendulums* as in *imaginary* ones; it would not follow; that ſhort Arcs would have any more of the cycloidal properties, than ſtraight lines have of the properties of ſhort Arcs; and if ſuch inaccuracies are admitted as mathematical reaſoning, we need not be ſurpriſed to hear it aſſerted, that there is no difference between a cycloid and a ſemicircle; *we may deceive ourſelves by ſuch reaſoning*, but cannot impoſe on nature; the ſmalleſt part of the *one*, for part of the *other*.

Suſpenſion.

113. As to the motion that may be communicated to the point of ſuſpenſion (94), I have only here to obſerve, that it may be more advantageouſly prevented by rendering the point of ſuſpenſion more immoveable, than by rendering the Vibration ſhorter; ſince by this means, we may preſerve the one advantage; without loſing the other. *Of this more hereafter.*

*As to the reſiſtance * of the Air.*

Its changes only to be conſidered.

114. I formerly have obſerved (27, 28), that we are only to conſider the alterations that happen therein; and if in this reſpect ſhort and long Vibrations are found on a level, *the latter* is to be preferred, for reaſons already given (89, 47).

Shortens the time of aſcent, as much, &c.

115. Since the *reſiſtance of the air* ſhortens *the time of aſcent* (17), as much as it prolongs *the time of deſcent* (17); let an aſcent, and deſcent, be taken together; and any change in the reſiſtance, can only affect their times, by rendering the Vibrations longer or ſhorter (19). *And therefore* †,

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* By the reſiſtance of the air, we are only to underſtand the effects of its *Vis inertiæ*, by which the motion of bodies paſſing through it is deſtroyed: *ſuch effects as ariſe from its different ſpecific gravities, independent of its Vis inertiæ*, ſhall be conſidered towards the end of this Eſſay.

† Sir ISAAC NEWTON takes notice in the 2d Corol. to Prop. 27. Prin. Math. V. 2. "That the time of deſcent of a funipendulous body, is ſomewhat more prolonged (by the reſiſtance of the air) than the time of its aſcent is contracted, *in proportion as the deſcent is longer than the ſubſequent aſcent*;" which is not the caſe in Clock-pendulums, where the time of deſcent is contracted by the action on the pallets: and if the reſiſtance ariſing from the *Vis inertiæ* of the air, tends to render the Vibrations ſhorter, and quicker in circular Arcs (19) in proportion to its denſity; the ſpecific gravity of the air independent of the *Vis inertiæ*, tends to render them ſlower, in the ſame proportion. See 6 Corol. to Prop. 24. of his Principles; where he ſays: "That the comparative weight is the motive force of a body in any heavy medium: and therefore does the ſame thing in ſuch a *non-reſiſting* medium, as the abſolute weight does in a vacuum." But of this hereafter.

Vol. 2.

116. The

RESISTANCE OF THE AIR.

Its effects leaſt in thoſe Vibrations, &c.

116. The iſochroniſm will be leaſt altered in thoſe Vibrations, that undergo the leaſt *proportional alteration* in their length (14), *from any change*, in the reſiſtance of the air; or in the maintaining power.

117. The reſiſtance that a Pendulum meets with from the air, bears a duplicate proportion to the length of the Vibration: and the reſiſtance that gravity makes to the aſcent of the Pendulum, is alſo in the ſame proportion. *Therefore*,

Reference, &c.

118. All that has been ſaid *concerning the comparative advantages of long and ſhort Vibrations* (from 29 to 48), *is* equally applicable *to the uniform reſiſtance of the air* *.

119. And, though the *whole reſiſtance* is much greater in long, than in ſhort Vibrations; the *change* that any *alteration in the denſity of the air*, will make *in the reſiſtance*; will bear *no leſs proportion to the whole reſiſtance* in ſhort Vibrations than in long: *And therefore*, (116, 118).

Long Vibrations preferable, &c.

120. *If no other conſideration than the uniform reſiſtance of the air, did take place*; THE

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* Here it is to be obſerved, that the uniform reſiſtance of the air, tends to diminiſh the effect of any change in the maintaining power, in the duplicate proportion of the Arc of Vibration. See Plate 1. Fig. 1 and 2. where the reſiſtance of the air as well as that of gravity may be repreſented by the perpendicular heights (117), (i. e. the verſed ſines,) ſo that the former muſt have a ſimilar effect with the *latter* in preſerving the Vibration of a more equal length, (41, 46, 47) and more iſochronal (14).

Resistance of the Air.

longer Vibrations in Clock-pendulums *are much preferable to the ſhorter*; nor do the *alterations that happen in ſuch reſiſtance* render them inferior (119) *.

Sir Isaac Newton's demonſtration not applicable to Clock-pendulums.

121. Some admirers of ſhort Vibrations, may urge what Sir Isaac Newton has wrote in the 2d Cor. to the 27th Prop. V. 2. of his Principia; but I may venture to aſſert, that if their attention in reading, is equal to his judgment in writing, they will not apply any part of what he there ſays, to Clock-pendulums:

His words, &c.

122. His *words are*, "That the ſhorter oſ-
" cillations are more iſochronal, and very ſhort
" ones are performed nearly in the ſame times,
" as in *a non-reſiſting medium* †."

Funipendulous bodies.

123. But let it be obſerved; that what He has demonſtrated, is expreſsly of *funipendulous bodies* ‡, to diſtinguiſh them, from ſuch bodies as have a maintaining power, and are kept in *conſtant motion.*

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* If a pendulum approaches near to a ſolid body, at the extremities of its Vibration, the repercuſſion of the air from ſuch body may tend to accelerate the deſcent; and ſo contract both, the times of aſcent and deſcent; on which account, Clock-pendulums ſhould have ſo much room as never to approach very near to the caſe.

† By a non-reſiſting medium is here meant, a medium deprived of its *Vis inertiæ*; and it is alſo implied that its denſity remains the ſame: otherwiſe the times of Vibration might be altered, even in a non-reſiſting medium.

‡ Bodies ſuſpended by threads.

RESISTANCE OF THE AIR.

124. HIS *meaning therefore, may be expreſſed thus*; ſince the reſiſtance of the air is in the duplicate proportion of the velocity, the longer Vibrations (where there is no maintaining power) muſt loſe more motion than the ſhorter ones do: and when the Vibrations become very ſhort, the reſiſtance is ſo ſmall, as to produce no ſenſible effect in the *length*, or *time*, of many Vibrations.

His meaning otherwiſe expreſſed.

125. *Any one who reads with due attention, his demonſtrations concerning Pendulums, will clearly ſee that he did not intend they ſhould be underſtood of ſuch as were applied to Clocks*; For,

Did not intend them to be applied to Clocks.

126. When he gives the method of cauſing a Pendulum to oſcillate in a cycloid (Prop. 50.) he ſuppoſes it, *a point*; and this ſuppoſition removes in his demonſtrations, any inaccuracies that may be found in Mr. HUGENS's; who expreſſly ſays *Clock-pendulums are meant*; and that the center of oſcillation is *a fixed point* within them. But of this more hereafter.

Reaſons.

127. *Moreover*, when Sir ISAAC demonſtrates the properties of Pendulums oſcillating in a cycloid (Prop. 51.) he ſays, "*That gravity alone*, "*acts on it*;" does not this even ſuggeſt, that the addition of any other power would deſtroy theſe properties?

128. If any further proof ſeemed neceſſary; that OUR INCOMPARABLE PHILOSOPHER did not mean, any of the demonſtrations of *funipendulous bodies*, to be underſtood of *Clock-pendulums*; and

He was well aware of, &c.

and that he was well aware of the changes that the application of a Clock would cauſe in the motion of a Pendulum.

Prop. 27. Corol. 2. Vol. 2.

129. *I might further obſerve*; that in the above cited corollary (121) he ſays, "But the "times of thoſe (Vibrations) which are performed "in *greater Arcs* are a little greater, becauſe "the reſiſtance in the deſcent of the body, *by "which the time is prolonged*, is greater, *in pro-"portion to the length deſcribed in the deſcent*, "than *the reſiſtance in the ſubſequent aſcent*, by "*which the time is contracted*."* This cannot be underſtood of Clock-pendulums, for it ſuppoſes *each ſubſeqnent aſcent* ſhorter than the preceding deſcent, which muſt terminate in reſt.

Reaſons.

Deſcent quickeſt in Clock-pendulums, &c.

130. But as ſoon as a Clock-movement is applied to a Pendulum, the deſcent is performed in leſs time than the aſcent, becauſe the action of the Wheels promotes the deſcent, and renders *each ſubſequent aſcent*, as long as the *preceding*; MOREOVER; what HE means to be underſtood of Clock-pendulums, he expreſsly mentions; See Cor. 2. Prop. 53. Pr. Math.

Further reaſons, &c.

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[*] Becauſe the reſiſtance, is in each, as the ſquares of their velocities: i. e. as the ſquares of the ſpaces deſcribed: if the ſpaces deſcribed remained the ſame, ſo would the reſiſtances: but this, not being the caſe; it is evident that what Sir ISAAC here ſays; is by no means to be underſtood of pendulums having a maintaining power.

Concluſion relative to ſhort Vibrations.

131. *It does not therefore appear*, that ſhort Vibrations derive any advantages *from their ſuppoſed affinity to the cycloid*; nor that Sir ISAAC NEWTON *any where meant*, *to recommend them in Clocks*; if the improvement of Clock-work, had been his motive for writing, it cannot be doubted, that he would have ſhewn as much Mathematical ſkill and accuracy in this, as in other ſubjects; but his views were more exalted.

Practice the criterion of all theory.

132. We muſt then judge of ſhort Vibrations, *ſolely*, *by the known properties of the circle*; and when we have compleated a probable theory, *experiment* will beſt determine its merits.

Another reaſon, &c.

133. One reaſon more, againſt ſhort Vibrations and heavy Pendulums; is, that the ſpring that ſuſpends the Pendulum, muſt increaſe in ſtrength, as the Pendulum does in weight; and ſince all ſprings alter their dimenſions, and conſequently their elaſtic force, by heat and cold; it follows, *That*

Changes in Pendulum ſprings.

134. Such changes, muſt in every ſpring bear a certain proportion to the whole elaſtic force; therefore, the changes that will ariſe in the forces of different ſprings by equal changes in their degree of heat and cold, will be to each other, *as the relative forces of ſuch ſprings*; And

Whole motive force of the Pendulum, &c.

135. Though I have hitherto conſidered the motive force of the Pendulum, as compoſed wholly of gravity and the action of the Wheels; (70), it would be abſurd, *not to add to them the elaſtic*

elaſtic force of the above ſpring, ſince it oppoſes the aſcent as much, and in the ſame manner, as it promotes the deſcent, and therefore has a conſtant tendency to ſhorten the times of Vibration *.

Effect of changes in the Pendulum ſprings.

136. And the effect that this elaſtic force will have on the times of Vibration, will be (80) *as the elaſtic force, to the motive force of the Pendulum*; And,

As the whole force of ſuch ſprings.

137. Since the alterations in this force, are, in different ſprings, *nearly as their whole force*, (134), it follows, that the relative effect that ſuch changes in the force of the ſprings would have on the times of Vibration, would be directly as the whole force of ſuch ſprings.

As the weight of the Pendulum.

138. But as the force of thoſe ſprings muſt increaſe as the weight of the Pendulum, the alterations that will happen in the times, will be (137) as the weight of the Pendulum; and conſequently when the momenta are equal, it will be much greater in ſhort, than in long Vibrations (89) †.

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* Some chuſe ſtiff ſprings, as they reſiſt moſt towards the extremities of the Vibrations, from which they acquire in ſome degree the properties of the cycloid: But any alteration in the action of this ſpring, has the ſame effect as an alteration, in power of gravity: which alters the times of Vibration, in cycloidal, as well as in circular Arcs.

† Nor will the certrifugal force of the longer Vibrations, at its loweſt points, nearly ballance this inconveniency in the heavier Pendulums.

139. Some

Limits of Vibration hinted.

139. Some may poſſibly expect that I ſhould here mention the exact limits for the length of Vibrations and weight of Pendulums, but though I have endeavoured to run a parallel betwixt the advantages of each, I do not pretend to preſcribe for the practice of others; and though *in common* I uſe Pendulums from 6 to 16 pounds vibrating from *three to ſix degrees*, *from the point of reſt**; I do not aſſert that thoſe limits are beſt; on the contrary, I imagine that Vibrations may advantageouſly be enlarged to ten degrees *on each ſide* the point of reſt; but this requires further improvement in Clock-work: of which more hereafter.

Addreſs to the reader.

140. In this enquiry into the nature of Vibrations, I have endeavoured to uſe ſuch reaſoning as may be underſtood by every man of ſound ſenſe, though not poſſeſſed of the advantages of a Mathematical education; and I expect that by having thus, as much as in me lies, increaſed the number of my judges; impartiality will believe, that I wiſh no overſight of mine to miſlead or paſs unobſerved.

141. Some further objections to cycloidal Vibrations are reſerved for an after part of this eſſay, when the different effects of ſuch alterations as happen in the denſity of the air are conſidered.

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* That is, Arcs from 6 to 12 degrees.

RECAPITULATION.

142. HAVING SHEWN, *That* the advantages of different Vibrations, in correcting the influence of any changes that may happen in the maintaining power are *(cæt. par.) in the duplicate proportion of their repective lengths* (41, 47).

243. *That* the *conſtant reſiſtance of the air*, has the *ſame* tendency to correct any irregularity in the maintaining power, and to limit the length of the Vibration; *that the action of gravity has* (118).

144. And *that* ſuch *uniform increaſe of friction* as takes place by increaſing the maintaining power, *cannot influence the performance of the Clock* (50, 60).

145. *That the reſiſtance of the medium* has the ſame effect in altering the length of Vibration, as *diminiſhing the maintaining power* would have (51, 52). And conſequently *what is ſaid of the former*, (41, 47), is equally applicable to *the latter*.

146. *That* ſhort Vibrations *derive no advantage* by being maintained by a ſmaller power in proportion to their momentum, than long Vibrations are (48 to 51).

147. *That* no method is yet inveſtigated for giving the *true cycloidal properties* to Pendulums, (98, 99); and that any remaining error is diminiſhed by enlarging the Vibration (41, 47).

148. *That* admitting all that Mr. HUGENS has demonſtrated of the cycloid; ſhort Vibra-

tions in a circle, *derive no advantage from their ſuppoſed affinity thereto* (112).

RECAPITULATION.

149. *That* the *reſiſtance* of the air can only alter the times of circular Vibration, *by altering their lengths* (115).

150. *That* Sir ISAAC NEWTON *has no where* recommended ſhort Vibrations for Clocks; nor did he intend that his demonſtrations of *funipendulous bodies* ſhould be *any how* applied to Clock-work (121 to 133).

151. *That* momentum may be acquired *to a greater degree* and *more advantage*, in long than in ſhort Vibrations (133 to 138), and, that on the whole, long Vibrations are inferior to ſhort ones in one article only; which takes its riſe from the imperfections of execution; and may therefore be remedied by proper care in the mechanic (113), as I ſhall ſhew hereafter.

Long Vibrations leſs influenced in every reſpect, than ſhort ones, &c.

152. FROM ALL WHICH, *it may be concluded, that long Vibrations are leſs influenced by equal cauſes, than ſhort ones: which concludes the firſt part of the theory of Clock-work* (5). I now proceed to the SECOND: in which many articles will occur, that will corroborate what has been already ſaid.

Second part of the theory, &c.

153. *The ſubject of enquiry in the ſecond part of this Eſſay is,* WHAT CONSTRUCTION OF A CLOCK, *tends leaſt to alter the iſochroniſm of the ſame Pendulum.*

INFLUENCES OF THE OIL ON THE PIVOTS.

Conſiderations referred, &c.

154. As the influence of heat and cold on the Pendulum, and the irregularities of action, with wheels and pinions, take place in almoſt all Clocks; I refer the conſideration of them to a ſubſequent place; and only obſerve here, *that in each of them*, equal cauſes always produce equal effects.

Influences on the oil irregular, &c.

155. The influences of heat and cold on the *oil* applied in Clocks, *is of a more irregular nature*; for the qualities of the oil, are through time changed by the motion of the Clock, in ſo much that *equal degrees* of *heat* and *cold* will have *different effects at different times*; which makes it impoſſible to apply a remedy by means of, the expanſion of metals; and it would even ſeem that a perfect remedy had been deſpaired of unleſs by diſcontinuing the uſe of oil: this is alſo big with difficulties, and at the end we will find, that we have (at a conſiderable expence) *only* ſubſtituted a ſmaller imperfection for a greater.

Propoſal.

156. I ſhall *here* endeavour to ſhew; *how this imperfection may be much reduced, and what conſtruction of a Clock will be leaſt influenced by it, when thus reduced.*

Smaller quantity of oil ſooner deſtroyed by motion, &c.

157. Since a ſmaller quantity of oil, is ſooner deſtroyed by motion, than a greater; the effect will be rendered leſs, and always more proportionable to the cauſe, by ſupplying the pivots with a greater quantity of oil, which ſhould be contained

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contained in a metal not ſo liable to corrode as braſs *; for moſt oils unleſs concentrated by cold, contain more or leſs of ſaline, aſcid or aqueous parts, ſometimes all the three; which corrode the braſs; and the parts thus corroded, mix with and deſtroy the oil: care muſt alſo be taken not to uſe a ſoft malleable metal however fine, for duſt, &c. will ſtick to it, and tear the pivots: I have uſed hardened ſteel for this purpoſe, *in preference to any other metal.*

Contains ſaline, &c. parts.

Steel buſhes.

158. If the ſame oil be applied to any number of Clocks, equal degrees of heat and cold will have equal effect on the fluidity thereof in each Clock, without regard to their moving powers: *Therefore,*

Foundation of the theory.

159. If there be any number of Clocks whoſe moving powers are as 5, 10, 20, 40, &c. *having the ſame oil applied, and equally expoſed*; any change of heat or cold will equally add to, or ſubſtract from, their moving powers (158); ſuppoſe one degree of diminution in each, then will the moving powers acting on the pallets, be as 4, 9, 19, 39; ſo that *the alteration, is to the whole moving power in each, inverſely as the moving powers to each other.*

Illuſtration by Clocks equally expoſed to cold.

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* The expence of diamonds or rubies, is the only reaſon of my not recommending the uſe of them. But I here treat of the improvement of Clocks, for domeſtic uſes, wherein expence muſt as much as poſſible be avoided.

160. But

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Immediate effect of any change, &c.

160. But the *immediate* alteration that any change in the moving power will cauſe in the meaſure of time, will be to the whole time, as the alteration in the moving power to the whole motive force of the Pendulum (80).

Momentum accumulates with the increaſe of power.

161. Every Clock continues to increaſe its Vibration *till the reſiſtance of the air*, &c. becomes equal to *the maintaining power*; and therefore, the momentum accumulated in the Pendulum increaſes with the maintaining power; and ſince the momentum is increaſed *nearly as the motive force of the Wheels*; and the *comparative influences of the oil* diminiſh in the ſame proportion (159); *It follows that*,

Its effect in the inverſe duplicate proportion of the motive force.

162. The influences of the oil, will affect the going of a Clock, *(cæt. par.) nearly in the inverſe duplicate proportion* of the motive force of the Wheels (161). And *therefore*,

Clocks ſhould move freely, &c.

163. Though the execution of all Clocks ſhould be ſuch as render their motion as free and eaſy as poſſible, no advantage is gained by uſing the ſmalleſt weights that will maintain the motion of the Pendulum; *but the contrary:* this anſwers well for proving the care and judgment of the workman, but ſo ſoon as that end is obtained, *the moving power ſhould be increaſed* in order to improve the performance (162).

The variation in time is greater with ſmall, than great weights.

164. Example: A Clock that will go for eight days with two pounds, will meaſure time much better, *if a weight of twelve pounds be applied*;

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applied ; for the momentum of the Pendulum will by this means be increaſed, nearly as twelve to two (161), and the influences of the oil, will be diminiſhed in the ſame proportion (160), therefore the alterations occaſioned in the meaſure of time, *by equal changes in the oil*, would be in *the former caſe*, to the alteration in *the latter* as thirty-ſix to one *.

Miſtake of uſing ſmall weights.

165. Thus it appears *how much thoſe are miſtaken, who uſe very ſmall weights to Clocks* : for though an increaſe of weight is attended with an increaſe of friction, it only argues that the longer Vibrations require more maintaining power in practice than in abſtract theory (50) †.

Greater on the pallets than pivots.

166. What has been hitherto ſaid of the influence of the oil, *is more particularly to be underſtood of that applied to the pivots* : for, though

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* I have admitted, that the momentum is increaſed exactly as the maintaining power, for the ſake of a ſimple illuſtration ; not with any view of deceiving : and if it appears that the advantages increaſe with the maintaining power, though not in the exact proportion here ſtated, my end is obtained.

† It alſo appears, that an increaſe of maintaining power is advantageous, even without regard to the increaſe of momentum acquired by it. Hence it is not ſo great an advantage in ſhort Vibrations, that they are maintained with ſmaller weight ; for if the maintaining power was as uniformly the ſame, as the exertion of gravity, it would conſtitute as advantageous a motive force : Hence it is not the *quantity*, but *the irregularities* of the maintaining power, that hurts the performance of Clocks : and therefore the moſt regular is to be preferred, without regard to the proportion it bears to the momentum of the Pendulum.

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it alſo applies to the oil uſed on the pallets, the effect of any change in it, is much greater than has been hitherto mentioned ; for any diminution in its fluidity tends *to deſtroy* the momentum which the Pendulum had already acquired, as well as to *diminiſh the maintaining power* ; here, action and re-action conſpire to alter the iſochroniſm of the Pendulum.

As the revolutions, &c.

167. If the influence of the oil on any pivot during one revolution, be expreſſed by one, the influence of two revolutions, will be two ; on three revolutions, three ; &c. *Therefore* the influence of the oil, *on any pivot in any given time*, will be *as the number of its revolutions.*

As the ſpace, &c.

168. The ſpace deſcribed is alſo as the revolutions ; therefore *the influence of the oil will be (cæt. par.) as the ſpace deſcribed.*

Comparative on each pivot, &c.

169. Thus, may the *comparative influence of the oil* on each pivot in a Clock be found, if allowances be made for their different diameters. Example : Since the ſwing wheel makes ſixty revolutions for one of the minute wheel ; if their pivots were of equal ſize, the influence of the oil on the former, would be to its influence on the latter as 60 to 1 ; but allowing the pivots of the minute wheel to be thrice as thick as thoſe of the ſwing wheel, the relative influences on them, will be as twenty to one.

ON THE PALLETS.

170. If it be deſired to repreſent the influence of the oil on each pivot in an eight-day Clock, it may be done as in the margin.

Uſe of the table.

Wheels.	Revolutions.	Mean ſize of the pivots.	Influence of the oil.
Firſt,	1	7	7
Minute,	12	3	36
Third,	96	1½	144
Seconds,	720	1	720

171. In the firſt column you have the Wheel; in the ſecond, its number of revolutions; in the third, the mean ſize of both pivots; and in the fourth, the influences of the oil: by which it appears; that *the influence on the pivots of the ſwing wheel* is nearly four times as great as on *all the other pivots in the Clock.*

On the pallets.

The influences of the oil ON THE PALLETS are next to be conſidered.—

Demonſtration, of the leaſt poſſible.

172. Let A B C, Plate 2d, repreſent the ſwing wheel of a Clock, and H K D the pallets; if the Pendulum be made to vibrate, the leaſt angle that will poſſibly allow the Wheel, to eſcape; the influence of the oil on the pallets during one Vibration, will be as the length of the plane F A or C D on which the Wheel acts (168), and the influence during two Vibrations, will be as both theſe planes; therefore, if A O, is made equal to F A and C D, together, it will repreſent the influence during two Vibrations; but A O, is greater than the Arc A L M, and therefore, will bear a greater proportion to any third quantity, and the influences are as the ſpaces (168); therefore the influence on O A, will bear a greater

proportion to the influence on the ſwing wheel pivots; than the influence on the Arc **A L M**, would bear to it: but let us here ſuppoſe the influence, *only as the Arc* A L M, then will the influence on the pallets, during one revolution of the ſwing wheel, be to the influence on its pivots, *as the diameter of the wheel*, to *the mean diameter of both pivots*.

Action, and re-action have effect.

173. It may here poſſibly be ſaid, that though this influence takes place at the ſame time on both the pivots, it does not ſo on the pallets; but let it be remembered, that on them, action and re-action have *each an effect* (166), but in no other part of the movement; therefore the leaſt influence *that can poſſibly take place on the pallets* (172), will be to the influence of both pivots of the ſwing wheel; *as the circumference of the wheel to the mean circumference of both its pivots*.

Wheel to its pivots, as 50 to 1.

174. We may reaſonably ſuppoſe, that the circumference of the ſwing wheel is to that of its pivots, as 50 to 1; in which caſe, the influence of the oil on the pallets, *with the leaſt poſſible vibration*, will be to the influence on the ſwing wheel pivots as 50 to 1 (173): but the influence of the oil on the ſwing wheel pivots, has already been proved equal to four times the influence on all the other pivots (171); therefore, *the leaſt poſſible influence, that the oil will have on the pallets, is two hundred times as great* as *the*

influence on all thoſe other pivots: or forty times as great as the influence on all the pivots, thoſe of the ſwing wheel included.

On the pallets to that on the pivots as 40 to 1.

175. I have hitherto *ſuppoſed the Vibration as ſhort as could poſſibly allow the Wheel to eſcape*, in which caſe, the influence would be the ſame; *whether the pallets were conſtructed on the* RECOILING *principle*, or *that of the* DEAD-BEAT; but,

With the dead-beat.

176. Let us *now ſuppoſe*, the pallets conſtructed on the principle of the DEAD-BEAT, and that *the Vibration is doubled*, then will the Wheel embrace the circular part of the pallet, and each tooth will move from F to P, and from P to F again; before it begins to act on the plane F A; therefore (168), *the influence of the oil* will now be, to *what it formerly was*, as *twice* F P together with F A, to F A; and if F P be to F A, as two to three, twice F P will be to F A, as *four* to *three*; and therefore (168), *the influence on the pallets will now be*, to *what it formerly was* (174), as *ſeven* to *three*; and *to the influence on all the pivots*, nearly *as ninety-two to one* *; and this I take to be the general proportion of influence on the pallets in Mr. GRAHAM's Clocks, and in the generality of others that go with ſmall weights,

PLATE II.

In Mr. GRAHAM's Clocks, &c.

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* Or to the influence on all the pivots, thoſe of the ſwing wheel excepted, nearly as 466 to 1.

INFLUENCES OF THE OIL.

and where the pallets take in twelve teeth of the ſwing wheel *.

177. *Let us now ſuppoſe the above pallets, conſtructed on the* RECOILING PRINCIPLE ; *and enquire what will be the influence on them ; all other circumſtances as formerly.*

PLATE II.

With a recoil.

178. Let A F be produced to H, and it will repreſent the plane on which the Wheel acts ; by the conſtruction of the figure, F O, will be greater than F A, for they ſubtend equal angles at the center ; but we ſhall here *ſuppoſe them equal.* Now, let the tooth C, eſcape the pallet C D, and the tooth M, will drop in the point F; when the whole Vibration is performed ; that is, when the Pendulum is at the extremity of its Arc, the tooth M, will be at O, from whence it muſt return to A, before it can eſcape the pallet. *Thus it appears*, that in each Vibration the tooth deſcribes on the pallet, a ſpace equal to thrice A F ; therefore, *the influence of the oil on the pallets,*

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* Plate 3. Fig. 3. exhibits at one view the length of the pallet, and the diſtances of the center of the verge from that of the ſwing wheel, according to the number of teeth of the Wheel which the pallets take in, from 2 to 12 : By which it appears, that the diſtance of thoſe centers, is the ſecant ; and the length of the pallets the tangent, of half the angle ſubtended at the center of the ſwing wheel, by ſuch number of teeth.

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pallets, during each Vibration, *will in this caſe be* to *the influence on* F A, as *three* to *one.*

To that on the pivots.

179. And (174), *the whole influence on the pallets* will here be, *to the influence on all the pivots*, as *one hundred and twenty* to *one*; but the influence with the DEAT-BEAT has been proved, to be to that on all the pivots, as ninety-two to one (176); conſequently, *the influence of the oil on the pallets*, with the RECOIL, is to *the influence with the* DEAD-BEAT, (in this caſe) as *one hundred and twenty* to *ninety-two.*

Additional on the pivots, its proportion.

180. I have in the above calculations conſidered the influence *on the pallets only*, but if we allow for *the additional influence on the pivots with the recoil*, the whole will be greater than above ſtated; for the whole influence on the pivots, will be as the ſpace deſcribed by the point of any tooth in the wheel during ſixty Vibrations; to the circumference of the Wheel.

On curve pallets.

181. In the above comparative view, the face of the pallet has been conſidered as a plain; but the demonſtrations will apply, ſuppoſing them curves; only obſerving that in ſuch caſe, the influence will be increaſed in the proportion that the length of ſuch curve bears to a ſtraight line joining its extremities; *and the relative influences* on all the parts of *thoſe two Clocks* may be repreſented as follows.

On all the pivots	With the *dead beat* — —	1
	With *recoiling pallets* — —	3

The

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On the pallets	The leaſt poſſible	40
	Dead-beat and double Vibration —	92
	Recoiling pallets and double Vibrat.	120*

182. Having thus conſidered the influences of the oil on the pallets, and ſhown that it will *always be greater (cæt. par.) with a recoil* than *dead-beat :* I now proceed to enquire ; *how this influence may be diminiſhed by the conſtruction of ordinary pallets.*

Dead-beat to prevent a recoil, &c.

183. An attentive view of Plate 2d may ſatisfy us, that the *dead-beat* is chiefly intended *to remove the recoil and its bad effects* ; and that in pallets, where friction and the influences of oil take place, *no advantage, is aquired by increaſing the time of reſt.* Example :

Illuſtration.

PLATE II.

Time of reſt conſidered.

184. If the Pendulum vibrate any angle O, K M, the ſlope of the pallet ſhould ſubtend the whole of that angle or nearly ſo, as P A : for if the ſlope only ſubtends one half of the angle as F A, the influences of the oil will be increaſed in the proportion that twice F P together with F A bear to P A ; but P F and F A together, are greater than P A ; therefore twice P F and F A, will be much greater than P A ; and conſequently (168), *the friction and influence of the*

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[*] It is not meant here to aſſert, that this proportion will univerſally hold ; for it will vary in proportion to the quantity of the recoil ; but will ever be greater with it than the dead-beat.

oil, will be increaſed in the ſame proportion, *by thus increaſing the time of reſt.*

How long it ſhould be.—

185. As all Clocks vibrate further when the oil is clean and fluid, than when it becomes dirty and glutinous, we muſt always allow the Arc of reſt as P F, to ſubtend an angle equal to the greateſt change that can happen from the different ſtates of the oil; nor ſhould any great latitude be taken here, ſince Clocks ſhould always be cleaned, when their Vibration is ſenſibly diminiſhed.

186. Thus it were well that in conſtructing pallets, on the principle of the dead-beat, more regard was paid to this conſideration; and, that the time of reſt, was made no longer than is *abſolutely neceſſary.*

Increaſe of recoil, or reſt: increaſe it.

187. But we daily ſee, that *ſome increaſe the time of reſt*, while others *increaſe the recoil*, each with intent to improve the performance: but on the whole, increaſing the time of reſt, where the influence of oil takes place, increaſes the evil, though not ſo much as an equal increaſe of recoil does (182).

PLATE II.

188. It may here probably be urged that the influences of the oil on the pallets, muſt always be greater with long Vibrations than with ſhort; for P A, is longer than F A; *but if this be generally the caſe, it does not follow*, that it muſt remain ſo; For,

As the length of the pallets.

189. In equal Vibrations, *thoſe influences are as the length of the pallets.* See Plate 3. Fig. 1. which

Influences of the Oil

Plate III. Fig. 1.

which repreſents the place of action of four pair of pallets, whoſe lengths are as 1, 2, 3 and 4; if the Arc of reſt, and ſlope, ſubtend the ſame angle in each; as repreſented by the dotted lines, it is obvious that the influences of the oil and friction, are in each, as the length of the pallets from the center of motion to the point of action.*

Pallets ſhortened.

190. Therefore when the Vibration is enlarged, the *pallets ſhould be ſhortened*, and care ſhould be taken *never to have them longer* than what is *abſolutely neceſſary*; for no advantage can be thus gained, and the diſadvantages are obvious (189).

Long pallets no advantage.

191. *As ſome are of opinion*, that a longer pallet will maintain the motion of a Pendulum, with leſs power than a ſhorter; I muſt once more refer to Plate 3. Fig. 1. where it will appear; that what is gained in power *by the length of the pallet*, is loſt *by the inclination of the plane on which this Wheel acts*; if it be propoſed to make the inclination equal in all the pallets, and thereby to acquire an advantage in proportion to their length, let it be remembered that if the power is made to act *four times as ſtrong*, it will only continue to act *one fourth of the time*, ſo that what is gained in power, is loſt in time. *On the whole*,

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* And the length of the pallets, *c. p.* depends on the number of teeth which they take in. See Plate 3. Fig. 3. (176).

192. Since

ON THE PALLETS.

No power can be gained by lengthening the pallets.

192. Since the power of the *ſwing wheel* is limited, any attempt to increaſe its effect, by lengthening the pallets, will be fruitleſs; for *it* cannot eſcape the pallets, however ſhort; before it has exerted all its force thereon. Example: Every mechanic knows that the exertion of gravity, on bodies deſcending by inclined planes, is always as the *perpendicular height*, and therefore, never attempt to gain power by *lengthening* the plane; the caſe is exactly ſimilar with regard to long and ſhort pallets: for if the Wheel be capable of exerting a certain force, in a whole revolution, it can exert no more than one ſixtieth of that force in a ſixtieth of its revolution; that is, during one Vibration.*

Why its effects not more ſenſible on the performance.

193. It may poſſibly be ſaid, that if the influence of the oil was ſo great *as above ſtated*, its effects on the performonce of Clocks would be more ſenſible than they are: To this it is anſwered; that if *no other* imperfection took place, this effect would become conſiderable; but ſince the friction on the pallets, *as well as the influence of the oil* increaſes as the ſpace which the teeth of the Wheel deſcribe on the pallets; while the oil is attenuated by heat, the increaſe of friction on the pallets, ariſing from the increaſe

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* And the progreſſive motion of the Wheel, in the one caſe, may properly be compared to the perpendicular deſcent, in the other; each, being the line of direction of the power, by which, its exertion muſt always be eſtimated.

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of Vibration *partly* compenſates the increaſe of power, and preſerves the length of Vibration more equal *c. p.* than if no friction took place, and *vice verſa.*[*]

Friction on them, cannot ballance it.

194. But the effects of friction on the pallets can never remedy the influences of the oil, for the former is of *a more uniform nature*, and *the latter very changeable.*

Different effects counteract each other, &c.

195. Heat lengthens the Pendulum rod of *a Clock*, and ſo tends to make it go ſlow; the ſame heat makes the oil more fluid; and by thus increaſing the action of the ſwing wheel, on the pallets, tends to make *it* go faſter [†].

196. Thus, *do the effects of heat and cold on the Pendulum*, *together with the friction on the pallets* (193), always counteract, and in many caſes overcome, *the influence of the oil on the pallets*, &c. (193, 195); and by this means, *the whole variation in the performance of Clocks*, bears a leſs proportion *to the whole cauſes*, than would happen *if they did not counteract each*

The whole Variations bear leſs proportion to the cauſes, &c.

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[*] It is not here meant, to recommend the friction on the pallets, as a deſireable remedy againſt any imperfection in the performance: for if it be diminiſhed to ſuch a degree, as to render the application of oil unneceſſary, the Vibration will by that means, be increaſed ſo as to be leſs influenced by any alteration in the tenacity of the oil on the pivots (41, 173, 174). It is therefore inſtrumental only, in diminiſhing an evil of which it is the cauſe, and which it never can ballance; nor can its advantage in any reſpect equal its hurt: as I ſhall ſhew hereafter.

[†] Particularly with recoiling pallets.

other ; or *if each was taken ſeparately*. ON THE WHOLE IT APPEARS,

ON THE PALLETS.

RECAPITULATION.

197. *That* oil is of a changeable nature, and that no perfect remedy can be applied for its effects by oppoſition (155 194).

198. *That* increaſing the moving power in Clocks, will diminiſh the relative effect of ſuch influence on every part of the movement and pallets (162).

199. *That* increaſing the quantity of oil will render its influence leſs, and more uniform (157).

200. *That* the *recoiling pallets* increaſe the influence of the oil and friction *on all the pivots*, as well as on the pallets : but the *dead-beat does not* (180).

201. *That* the influence and the friction on *recoiling pallets*, (cæt. par.) are greater than on thoſe conſtructed on the principle of the *dead-beat* (181).

202. *That* the influence of the oil and friction, is leaſt on thoſe pallets, where the *recoil*, or *time of reſt*, is leaſt (187) : Therefore,

203. *That* the ſlope (or planes of action) of the pallet ſhould nearly ſubtend the whole angle of Vibration (184), where friction takes place.

204. *That* the influence of the oil is greater in pallets whoſe place of action is a curve, than thoſe that are ſtraight (181).

INFLUENCES OF THE OIL

205. *That* the influence increaſes *(cæt. par.)* as the diameter of the ſwing wheel (172) *.

206. *That* the influence of the oil, and friction increaſes as the length of the pallets (189).

207. *That* no advantage is acquired by long pallets, *but the contrary*; and therefore they ſhould be made as ſhort as circumſtances will allow (191) †.

RECAPITULATION.

208. *That* the influences of the oil and friction may be as much diminiſhed in long as ſhort Vibrations (190, 172).

209. *And, that* the friction on the pallets counteracts the influences of the oil, *but never can ballance it* (193, 194).

210. Thus have I endeavoured to ſhew, *how the changes that happen in the fluidity*, &c. *of the oil, do influence the performance of Clocks*; *and how far the effect may be diminiſhed* WITHOUT MUCH EXPENCE: and if what I have here advanced proves any how inſtructive to thoſe who know leſs; or procures a better inveſtigation, from thoſe who know more of this matter; my end is anſwered.

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* Here the friction does not increaſe as the influence of the oil; as will appear, when we conſider the nature of the horizontal wheel and cylinder.

† This rule only applies in pallets, where friction takes place; but I ſhall ſhew hereafter, how a conſiderable advantage may be gained by lengthening ſuch pallets, as have neither friction nor recoil.

ON THE PIVOTS DIMINISHED.

211. *I now proceed to enquire into the different methods that have been heretofore uſed, for removing the influences of the oil.*—

Friction accumulates.

212. When two hard bodies rub againſt each other, there ariſes a reſiſtance which we commonly call *friction*; and though by experiments of ſhort duration, repeated at different times, we find no ſenſible difference in this reſiſtance; it increaſes by continuation; ſo as in ſome caſes to equal the moving power.—

Example.

213. If a common Clock be ſet a going without any oil, it moves pretty freely at beginning: in time, loſes its Vibration; and in the end, comes to reſt; and if the rubbing be conſtant, the times in which this will happen, will be ſhortened by increaſing the preſſure, or relative velocities of the rubbing ſurfaces *.

A probable reaſon, why.

24. All ſolid bodies are heated by friction, or attrition of any kind; and *the heat* thus generated is at leaſt in ſome degree, proportioned to the force and velocity with which the bodies act on each other; nor is it improbable, that *it* opens the pores of metals or produces ſuch other changes in their textures, as to occaſion *this increaſe of friction*; to prevent the pernicious effects *of which*, OIL has been applied to Clocks; there-

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* The application of oil will immediately recover the motion; which tends to prove, that ſuch decreaſe was not ſolely owing to ſuch roughneſs of the ſurfaces, as commonly takes place.

fore, if friction be removed, by any mechanical means, the application of IT will become unneceſſary, and its influences no longer take place.

Friction pullies.

215. *Thus* have friction pullies been introduced, and if materials and execution could be ſuppoſed perfect, and no regard paid to expence, *the friction of the pivots* might by their means be ſufficiently reduced for common purpoſes; nor would I diſapprove the uſe of them, unleſs a more ſimple and effectual remedy could be offered; of which more in its place.

Winding up every half minute.

216. The next attempt of removing the influences of oil *from the pivots*, we owe Mr. HUGENS, which contrivance he deſcribes thus in his *Horologium Oſcillatorium, publiſhed in the year* 1673; "To that Wheel which is next the "Pendulum, and has its teeth cut like a ſaw, we "hung *a ſmall weight* by a ſlender chain, by means "of *which*, that Wheel alone was moved, all the "reſt of the machine anſwering no other pur-"poſe than the winding up that ſmall weight "every half minute."

When firſt applied.

217. Mr. HUGENS informs us that he applied the above contrivance, to two *ſpring-clocks* that were ſent to ſea in the year 1664, in order to diſcover the Longitude; and that their motion was by *the above means* rendered more uniform (at land) than in any of his former Clocks: he gives a full deſcription of them, with an account

of their ſucceſs, in the above cited book, from page 16, to 21, to which I refer the curious.

Advantages of this contrivance.

218. The advantage of this ingenious contrivance is manifeſt *in ſpring-clocks that are fixed at land :* for we may *thus*, have the conveniency of the ſpring (as the firſt mover); and the more uniform action of gravity *for maintaining the Vibrations* ; but we are not to conclude, that by this means Clock-work is perfected.

Its utmoſt effect.

219. *I have already ſhewn* (174) that the leaſt poſſible proportion that the influence of the oil *on the pallets*, bears to the influence on *all the pivots*, in an eight-day Clock, (thoſe of ſwing wheels excepted) is as 200 to 1. *Therefore*, this contrivance, can only remove a 200th part of the whole influence of the oil in an eight-day Clock *.

Comparative advantage conſidered.

220. Some may poſſibly think, that great advantage is acquired by removing the irregularities of action in the Wheels ; without conſidering that this little weight muſt be wound up every half minute ; and that the ſwing wheel muſt *as oft* unlock the part which winds it : *thus*, there ariſes a periodical inequality in the action of the ſwing wheel on the pallets, which is no more innocent than the periodical fluctuations in the action of Wheels and pinions, as ſhall

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* See the note to par. (176): by which it appears, that the influence of the oil on the pallets, and the pivots of the ſwing wheel together ; is 466 times as great as on all the other pivots in an eight-day Clock, though here, ſtated only at 200.

be further ſhewn hereafter. ON THE WHOLE IT APPEARS,

Concluſion relative to its uſes in ſtanding Clocks.

221. *That even in fixed Clocks*, this contrivance ſerves only to take off the imperfections of the main ſpring *ſo as to render the action on the pallets* as uniform *as in Clocks wherein gravity is the firſt mover*; and *to remove a* 200*th part* of the influence of the oil on the whole movement (174).

The contrivance ingenious.

222. I would not be underſtood by this inquiry, to depreciate an invention that indicates as much genius as ſome others of more utility; nor wantonly to detract from the merits of a perſon to whom Clocks owe their greateſt improvement; *I have ever preferred demonſtration*, to *opinion*, nor is the leaſt diſreſpect meant, whereever *the former* is oppoſed to *the latter*.

Not ſo advantageous in portable machines as above ſtated.

223. When I treat of Watches, it will appear *that the advantages of the above contrivance cannot be ſo great in any* PORTABLE MACHINE *as above ſtated*; and that it is more than probable, it hurts the performance; but let us now *ſuppoſe*, that it has all the deſired effect, and that the influences of the oil on *all the pivots* be totally remedied; the influence on the pallets ſtill remains; and conſequently $\frac{1}{40}$ only of the whole influence on the Clock is removed (181)*.

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* What is admitted at the cloſe of this paragraph, is intirely for the ſake of illuſtration; for this contrivance has no tendency to remove or diminiſh the influence of the oil on the ſwing wheel pivots, therefore its utmoſt advantage is ſtated (221).

ON THE PALLETS, DIMINISHED.

224. If any attempts have been made by the mechanics of the laſt age, towards removing the influence of the oil from the pallets, I am unacquainted with them; and though many have been made by thoſe of the preſent, it does not appear that they have been attended with all the wiſhed for effect; *for it is neceſſary, not only to remove the influences of the oil*; but *that no other cauſe be introduced that can be productive of ſimilar effects*.

Introduction.

225. I have ſeen pallets of a very ingenious conſtruction, with Mr. *John Harriſon* of *Red-Lion-Square*, and with Mr. *Hindley* of *York*; in each of which, the friction and influences of the oil were *almoſt annihilated*; but if I miſtake not, in removing theſe, *other imperfections have been introduced*; which, however ſhort of *the former*, merit ſerious attention.

Pallets by Meſſrs. HARRISON and HINDLEY.

226. The contrivances uſed by each of thoſe gentlemen, *ſo well known for their mechanical abilities*, were much of the ſame nature; nor did they differ materially in principle in any article that I could ſee; but Mr. *Harriſon* informed me; "that in his regulator, the action of the Wheel "on the Pendulum was the ſame with the action "of gravity thereon *: nor do I in the leaſt

Much of the ſame principle.

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* By which I underſtood, that the action of the ſwing wheel on the pallets, increaſed and diminiſhed in every part of the Vibration, in the very ſame manner that the action of gravity did on the Pendulum-ball; i. e. that the action was in every part, as the verſed ſine of the angle contained between the center of oſcillation of the Pendulum, and its point of reſt.

INFLUENCES OF THE OIL DIMINISHED.

doubt the aſſertion, though I have never ſeen, thoſe pallets; but cannot conceive what real improvement can follow; however, to the beſt of my remembrance, no ſuch attempt was made in Mr. *Hindley's*, but *the following articles were common to both their pallets, that I did ſee* *.

Articles that are common to both.

227. Firſt, *That* the teeth of the Wheel, *do not* rub on the *pallets*, but continue to act (or preſs) *on them* alternately during their reſpective Vibrations.

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* We are informed in the Phil. Tranſ. Vol. XLVII. pag. 517. and in the Supplement to Mr. HINTON's Dict. of Arts, &c. (See PENDULUM), "that this manner of applying the action of the "Wheels to the Pendulum, prevents its being affected by the "different reſiſtance of the air:" BUT I cannot imagine, that ſo ill-grounded an aſſertion, was thus publicly made with Mr. HARRISON's conſent: when it requires but a few minutes reaſoning, to prove, that ſuch an application of the maintaining power, muſt be hurtful to the performance of the Clock, by increaſing the effects, which, *any alteration* in the denſity of the air, would otherwiſe have on the meaſure of time.

Does not any *increaſe* of denſity (or reſiſtance) in the air diminiſh the angle of Vibration? and conſequently; this accelerating effect on the pallets (note 226); how then can the *latter* ballance the *former*, when the one increaſes as the other diminiſhes? And, admitting that this accelerating effect, did increaſe and diminiſh with, the denſity of the air, its effect on the meaſure of time, would be no better than above ſtated: unleſs we ſuppoſe, that the time of aſcent of a Pendulum, as well as the time of its deſcent, is increaſed by the reſiſtance of the air: But Sir ISAAC NEWTON informs us, That the time of aſcent is ſhortened, and the time of deſcent, lengthened by ſuch reſiſtance: nor is it difficult, (if it was neceſſary) to confirm his aſſertion by experiment: but of theſe matters more in their proper place.

Introduction to a Recoil in general.

228. Secondly, *That* the *one pallet* cannot diſengage itſelf from the Wheel, till the *other* begins to act, ſo as to cauſe a *recoil*, or retrograde motion of the Wheel; *which* was much more conſiderable in thoſe ſcapements, than in common ones.

229. *Thirdly*, *That* during the progreſſive motion of the Wheel, *a ſlender ſpring is bent*, that diſengages the pallet from the Wheel, *ſo ſoon as the recoil begins*.

230. Fourthly, *That* when the pallet is thus thrown from the Wheel, it is received by *another ſpring*, the office of which, is to keep it in a certain poſition, in which the teeth of the Wheel may always find it.

231. Fifthly, *That* during the retrograde motion *of the Wheel*, thoſe *laſt mentioned ſprings* are bent, by which means they oppoſe the aſcent of the Pendulum, and by their unbending, promote its deſcent.

Concluſion deferred.

232. *The concluſion concerning thoſe pallets muſt be deferred, till the effect of a* RECOIL *in general is explained*; to which I now proceed.

233. I have formerly obſerved; that the DEAD-BEAT was invented to remove the bad effects of *a recoil* (183); and *ſhewn*; that the influences of the oil and friction, is greater on pallets that have a recoil, than on thoſe that have none (182): *I now enquire into the comparative*

advantages of the DEAD-BEAT *and* RECOIL, *when neither friction, nor influence of the oil take place.*

All pallets reducible to TWO CLASSES.

234. All pallets whatever, muſt have *ſome recoil*, or *no recoil:* if *the former*; they take their name from thence: if *the latter*; they belong to the DEAD-BEAT: and thus may all pallets be reduced to TWO CLASSES: *and what I am now to obſerve of thoſe two kinds of pallets, will apply* WITHOUT EXCEPTION, *in all the variety of conſtructions that can poſſibly be invented*; ſince *it wholly depends on the quantity of recoil*, independent of all other circumſtances.

General uſes of the maintaining power.

235. The action of the Wheels, in all Clocks, ſerves to maintain the Vibrations; and their revolutions, give the number of Vibrations; theſe are ends, which the maintaining power muſt anſwer in all Clocks; but ſome have attempted to render the Vibrations more iſochronal, by giving a recoil; and thus making the action of the Wheels oppoſe the aſcent of the Pendulum at the extremity of its Vibration; and they ſeem to prefer this oppoſition of the Wheels, to the more *unalterable* oppoſition of gravity; becauſe the former increaſes and diminiſhes as the maintaining power; and conſequently, oppoſes the aſcent moſt, when it has the greateſt tendency to enlarge its limits: but *this imaginary advantage vaniſhes*, when we conſider, That;

Uſed by ſome to render the Vibrations more iſochronal.

PLATE II.

236. When the tooth C, Plate 2. is diſengaged from the pallet C D, the tooth M, will drop

OF A RECOIL IN GENERAL.

drop on the pallet H A at F, and as the Pendulum continues its progreſs, the Wheel will have a retrograde motion on the pallet; ſuppoſe, from F to O; it is obvious that the Wheel *will promote the deſcent and lengthen the next aſcent* by its motion from O to F; *as much as it oppoſed and contracted the aſcent* by its motion from F to O; and thus, *the action* from O to F, and *the reſiſtance* from F to O, do exactly ballance each other, ſo far as relates to the length of Vibration; And therefore,

Can have no tendency to limit the Vibration.

237. A RECOIL *can have no tendency whatever, to render the length of the Vibrations, more or leſs equal*; *nor to maintain the motion* *.

Nor to maintain the motion.

238. It is well known that any increaſe in the power of gravity, accelerates the motion of a Pendulum, *and ſhortens its time of Vibration*; and that *the times of aſcent and deſcent*, are equally contracted by this increaſe of gravity (17). Hence we may with truth infer, THAT *whatever oppoſes the aſcent of a Pendulum*, ſhortens its time of Vibration as much as *if it had promoted the deſcent*. Therefore, *any power that both oppoſes the aſcent*, and *promotes the deſcent*

Effect of gravity conſidered.

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[*] The effect of friction on the pallets will be conſidered fully hereafter, and ſhewn to be very hurtful to the performance, even though it has a tendency to preſerve the Vibrations more nearly of an equal length.

of a Pendulum; muſt produce a double effect on its times of Vibration *.

Recoil has a twofold effect on the times.

239. And *thus it appears* that any change, in the action of the Wheels, *during the time of recoil*, will have a double effect in altering the natural times of Vibration (238), *without the leaſt tendency to render the length thereof more equal* (237)†.

Space deſcribed as the impreſſed force.

240. If a certain impreſſed force, give a certain velocity, a double force, will give a double velocity; a triple force, a triple velocity, &c. and the ſpaces deſcribed in equal times, will be as the reſpective velocities: *that is*, as the reſpective forces impreſſed.

Impropriety of too much limiting the Vibration.

241. Thus *if the impreſſed force and velocity of a Pendulum be doubled*, and the length of Vi-

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[*] Here it is to be obſerved; that any power co-operating with gravity, contracts; and the ſame power oppoſed to it, prolongs, the times of Vibration. Hence whatever power, acts during the time of aſcent, and promotes it; or oppoſes the deſcent, will prolong the times; and this ſhould be carefully attended to: for on this principle, the maintaining power may be applied, in ſuch manner as either to prolong or contract the natural times of Vibration.

[†] If it ſhould be urged that the recoil may render the times of Vibrations of different lengths more iſochronal, without having any tendency to limit their lengths; the mode and quantity of recoil ſhould be inveſtigated with as great accuracy as the cycloidal properties; in which caſe it will altogether be unneceſſary and improper to apply the cycloidal cheeks; nor can ſuch an inveſtigation as above mentioned, be made, before each ſeparate effect that the application of a Clock has on the Pendulum, are accurately aſcertained; and even then, it is liable to all the ſame objections with the cycloidal Vibrations; of which in their place.

bration remains the ſame, *the number of Vibrations will be doubled*; but if the length of Vibrations be *alſo doubled*, they will be performed in the ſame times, as thoſe of half their length with half the velocity; *and univerſally*; if the length of Vibration increaſes, as the impreſſed force, the times will be equal; and on this account *it would be very improper to give a recoil*, on the ſuppoſition that it did render all the Vibrations more nearly of an equal length *.

Difference in the theory of detached, and Clock-pendulums.

242. It may poſſibly be urged by ſome, that the reſiſtance is greater at the extremities of cycloidal, than circular Arcs; and therefore, that no error can ariſe by thus increaſing the reſiſtance at the extremities of Vibrations in circular Arcs: but let me beg of thoſe to recollect; that *all the demonſtrations concerning cycloidal Vibrations*; ſuppoſe, that the action on the Pendulum in its deſcent, is exactly equal to the oppoſition with which it meets in its aſcent; which is not the caſe in Clock-pendulums; for the velocity in their deſcent, is greater than in their aſcent: and that more, or leſs, in proportion to the length of Vibration; even beyond what happens in detached Pendulums.

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* The ſame objection, with many others, ſtand in the way of correcting the length of Vibration, by an increaſe of friction. See (259, 260).

243. And

OF A RECOIL IN GENERAL.

Properties of the cycloid cannot with any propriety recommend a recoil.

243. And though certain properties have been demonſtrated of the cycloid; it does not follow, that every curve that deviates from a circle poſſeſſes thoſe properties, even when gravity alone acts: and much leſs, when any foreign power is applied; *therefore*, the cycloidal properties in detached Pendulums vibrating in a non-reſiſting medium; can by no means recommend a recoil, with thoſe applied to Clocks.

When too great in circular Vibrations.

Never to be admitted in cycloidal Vibrations.

244. *On the whole, we may be well aſſured*, that in all caſes where an increaſe of weight or maintaining power, makes a Clock go faſter; the recoil is too great: nor can it be ſuppoſed, that any, who have art enough *to make the center of oſcillation of a Pendulum deſcribe the true* CYCLOIDAL *curve, and faith enough in* ITS *properties*; would think of giving a recoil, to correct *thoſe Vibrations that are (by their theory) already perfect* *; from which appears the abſurdity of applying cycloidal cheeks with a recoil: but of this more hereafter.

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[*] As the recoil is intended to co-operate with the action of gravity on the Pendulum, in ſuch manner as to render its motive force in every part of the Vibration, as the diſtance from the loweſt point; the mode and quantity of ſuch recoil muſt be demonſtrated with the ſame certainty, at leaſt, as that of the cycloid: and I imagine that *this* will be much more difficult than *that*; not to mention the much greater difficulties of execution in the latter, and the uncertainty, relative to the theory of the former when applied to Clocks.

OF A RECOIL IN GENERAL.

Meſſrs. HARRISON and HINDLEY's pallets reſumed.

245. *I now reſume the conſideration of thoſe* PALLETS *wherein the friction and influences of the oil have been removed*; the reader will pleaſe here to peruſe from Par. (227 to 232).

Suppoſition.

Render the moſt perfect maintaing power unequal.

246. Let us here admit, *that the action of the ſwing wheel is as uniform as gravity*; it has at each Vibration *not only to maintain the motion of the Pendulum*, but alſo *to bend a ſmall ſpring* (229); therefore, whatever power is neceſſary to bend this ſpring, muſt be deducted from the maintaining power: and as all ſprings alter their ſtiffneſs by heat and cold; *that part* of the action of the ſwing wheel, that maintains the Vibration, can no longer be uniform, than the air is of the ſame temperature: and *thus*, will the length of Vibration *be altered*, and *the accelerating effects of the recoil take place* (239), *and alter the times of Vibration:* even ſuppoſing the cycloidal properties perfect, and the denſity of the air invariable.

Another defect.

247. Again; *becauſe thoſe ſprings that are bent during the recoil* (231), are liable to the ſame changes; they will produce *the ſame effect*, with *an equal change in the maintaining power during the recoil* (239). And,

Further conſiderations.

248. However trifling thoſe articles may at firſt appear, they become of more weight, when we conſider; *that they operate in that very part of the Clock where they produce the greateſt poſſible effect, on the meaſure of time*; and that

PALLETS WITHOUT FRICTION.

thoſe ſprings are ſo ſmall, as to be affected by the leaſt changes in the temperature of the air ; nor can thoſe effects be thoroughly remedied by a *gridiron*, or any other Pendulum, ſince *they* feel ſuch ſmall changes, as cannot ſenſibly affect ſuch thicker pieces of metal ; *add to this*, that an alteration of one 86,400 part of the time of each Vibration, will amount to *an error of one ſecond per day* ; a 604,800 part, in the time of Vibration, to *a ſecond per week*; and a 2,592,000 part, to an error of *one ſecond per month*.

Manner of applying the maintaining power.

249. As to the property mentioned in Par. (226), it does not appear to me that any advantage is gained by it in maintaining the motion of a Pendulum : *See Sir* ISAAC NEWTON's IId *law of motion*, where he ſays, "If any force "generates a motion, a double force, will ge-"nerate double the motion ; a triple force, "triple the motion ; *whether that force be im-"preſſed altogether and at once*, or *gradually "and ſucceſſively*" (237). And ſo far as regards the meaſure of time, *it is hurtful* ; as will appear hereafter.*

250. And as to the iſochroniſm of the Vibration, when the *dead-beat* is applied ; I ſhall hereafter ſhew in *what caſes*, it is beſt *to apply the*

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[*] It may be proper however, here to obſerve, that this method is preferable to others, wherein the recoil (being undetermined) may bear a greater proportion to the angle of Vibration.

maintaining power, gradually and ſucceſſively; and *in which*, it may more advantageouſly be applied *nearly at once*; leaving thoſe who better conceive the advantages of a recoil to give a like inveſtigation when it is uſed.

PALLETS WITHOUT FRICTION.

General remarks on their advantages, &c.

251. I would not be underſtood to depreciate, or *totally diſapprove* this ingenious invention: or to aſſert, that no good performance can be obtained when theſe pallets are applied; on the contrary, I think them preferable to any that I have yet ſeen *wherein the influence of the oil takes place*; but a proper regard muſt here be paid to *what has been ſaid concerning the diminution of the influence of the oil* (164); for whatever be the cauſe of any change in the maintaining power, *the effect on the meaſure of time*, will be *(cæt. par.) as ſuch change*, to *the whole power*; this argues for great maintaining power and long Vibrations.

Inconveniences brought into one point of view.

252. *If it is proved*; that the uſe of ſprings in pallets, *renders the effect* of the moſt perfect maintaining power *unequal* (246, 247); that *a recoil*, increaſes the effect of any ſuch change (239); and that *any alteration in the ſtiffneſs of thoſe ſprings that act during the recoil*, cooperates with the action of the wheels *during ſuch recoil*, in altering the times of Vibration (247):

Concluſion.

253. *It naturally follows*; that however ſmall the effect of thoſe IMPERFECTIONS, *the performance*

PALLETS WITHOUT FRICTION.

mance of Clocks will be improved, by totally removing them (248).

Motive for this examination.

254. If I have here pointed the way, to further improvement, my end is obtained ; and when it is conſidered, that I propoſe hereafter to remove every imperfection ſo far as the nature of things will permit ; and conſequently, that every difficulty and imperfection that I now mention, do in that caſe, become ſo many weapons againſt me ; candour will allow, that no other motive, than a real deſire of improvement could have induced me to this examination.

Introduction.

255. Having pointed out the diſadvantages of a recoil, and obſerved that the *dead-beat* was invented to remove them, it may be thought ſuperfluous to ſay any thing more on that head ; But,

256. *As the imperfections and properties of all objects, become the more obvious of being viewed in different lights* ; I ſhall now endeavour to ſhew the advantages of the DEAD-BEAT, in a manner different from what I have hitherto done ; by which it will appear, that ITS comparative advantages, to the RECOILING principle, are greater than I have hitherto ſtated them.

General remarks.

257. When a Pendulum is actuated *by the power of gravity only*, it riſes to the ſame height from whence it fell ; *allowing for the reſiſtances of the air*, &c. Therefore, if the action of the Wheels *in the deſcent of a Pendulum* be equal to the

DEAD BEAT FURTHER CONSIDERED.

the reſiſtances *in the deſcent and aſcent together*: the *former* will at each Vibration, communicate as much motion as the *latter* deſtroys.

Vibrations continue equal, &c.

258. And the velocity and length of Vibration, will continue uniformly the ſame while *this equilibrium* is preſerved. But,

Increaſe, &c. as the maintaining power.

As does the velocity of deſcent.—

259. If the maintaining power be any how *increaſed* or *diminiſhed*, ſo will *the Vibration*; till the reſiſtances of the air, &c. equal the maintaining power; and *the velocity of the deſcent*, will increaſe with the power (257)*. Therefore,

Deſcents quicker than the aſcents in Clock-pendulums.

260. The deſcents in the longer Vibrations, will be comparatively quicker than thoſe of the ſhorter (240), in this caſe, than in detached Pendulums †.

Time of aſcent in them, the ſame as in detached ones, cæt. par.

261. And ſince the Pendulum in its aſcent is not any how connected with the action of the Wheels *(as with a recoil)* it will *aſcend agreeable to the laws of detached Pendulums*; in which caſe, Mr. HUGENS has demonſtrated that 29 of the longeſt Vibrations, are equal in time, to 34

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* But if we ſuppoſe the maintaining power applied in the time of aſcent of the Pendulum; it leaves room for ſome exceptions. But as thoſe matters are fully explained where I treat of watch pallets, I leave the application here as no improper exerciſe for the reader's genius and attention; as ſufficient data are already furniſhed for the inveſtigation.

† This, among many other circumſtances, is entirely overlooked when cycloidal cheeks are applied.

of the ſhorteſt, of the ſame Pendulum, *independent of the reſiſtance of the air*[*].

The alteration in the time of a whole Vibration leſs, than in detached pendulums.

262. Now ſince in Clocks with a DEAD-BEAT, *the deſcent is quicker* (260), and *the aſcent is ſlower* (19) in the longer than on the ſhorter Vibrations; the alterations in the time of an aſcent and deſcent taken together, will bear a leſs proportion to the change in the *length* of Vibration, than in detached Pendulums; where the times of *aſcent* and *deſcent* increaſe or diminiſh *together*[†].

Dead-beat diminiſhes the effect of any change, &c.

263. And *thus*, does the *dead-beat* diminiſh *the natural effect* of any change that may happen in the length of circular Vibrations; whether occaſioned by an alteration in the moving power, or in the denſity of the air:

264. In all that has been ſaid (from Par. 233) *neither friction, nor the influences of the oil*, are ſuppoſed in the leaſt degree to take place; and therefore, the leſs they do, the better will the theory and practice agree; *I have already ſhewn* (184), that in pallets where the influence of the oil takes place, ſuch influence is increaſed by increaſing the time of reſt.

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[*] It may here probably be ſaid, that in pallets where *friction* takes place; the natural times of Vibration, (during the reſt of the wheel) will be influenced *thereby*: but we muſt not forget, that ſuch friction, oppoſes both aſcent and deſcent equally and thence corrects itſelf (238); ſo far as uniform friction only, is conſidered.

[†] On this account, the cycloidal curve as hitherto inveſtigated cannot have the deſired effect on Clock-pendulums: with, or without, a recoil.

265. *And*

Maintaining power gradually applied.

265. *And alſo* (185) that the ſlope, or place of action in ſuch pallets, ſhould, as nearly as can be, ſubtend the whole angle of Vibration; *which implies*, that the maintaining power ſhould be applied *gradually and ſucceſſively*, and *this may ſerve as a general rule, in all pallets where oil is uſed* *.

Applied at once.

266. But the contrary ſhould be obſerved, *of ſuch pallets as have neither friction nor influence of the oil, during the time of reſt*; for by this means, the influences of the oil, *during the time of action*, will be diminiſhed †.

May be applied in either way.

267. Where *the maintaining power* is perfectly invariable, and where the iſochroniſm of the

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[*] I ſhall ſhew hereafter, that when the influence of the oil on the pallets is removed; the effect of any alteration in the maintaining power, on the meaſure of time, will be *(c. p.)* as the time of action on the pallets to the whole time of Vibration; but this will not apply where oil is uſed to the pallets.

[†] In all pallets where the action of the Wheel is ſuſpended during part of the time of Vibration; and where the maintaining power is not perfectly invariable; the performance will be improved by applying the action of the Wheel, in ſuch manner that one half its exertion take place in the deſcent, and the other in the aſcent of the Pendulum; for without particular regard to this, the Vibrations of Clock-pendulums, whether circular or cycloidal, can never have their natural properties (238). This matter will be fully explained and exemplified, when I treat of Watch pallets, (where a ſtrict attention to it, becomes more neceſſary); only obſerving, that what is there ſaid of the action of the ballance-ſpring, is here to be applied to the action of gravity on the Pendulum. It will alſo appear why it is more advantageous to apply the action of the Wheels to the Pendulum in its aſcent than deſcent.

Pendulum is neither influenced by friction nor the changes in the oil; *it matters not, whether it be applied all at once, or gradually*; I do not here mean, that in ſuch caſe, the manner of applying the maintaining power will not alter the whole time of each Vibration; nor do I pay any regard to ſuch effect, provided it be uniformly the ſame in each ſucceeding one: *for ſuch uniform effect*, is corrected by the length of the Pendulum.

No fair comparative trial yet made of the dead-beat and recoil.

268. It may probably be alledged, that more is here advanced in favour of the DEAD-BEAT, than agrees with the general comparative obſervations on the performance of Clocks conſtructed on the principles of the *dead-beat* and *recoil*: but WHOEVER *recollects* what has been ſaid, *concerning the maintaining power* (164), *length of Vibration* (41), and *length of pallets* (189); will probably agree with me, *that no fair comparative trial has yet been made of the principles of the recoil and dead-beat.*

Maintaining power greater with the recoil than the dead-beat.

269. Is not the maintaining power always much greater *in common Clocks with recoiling pallets*, than in *the fineſt regulators with a* DEAD-BEAT? frequently as 3, 4, or 5 to 1?

Vibration longer with the recoil.

270. Is not the Vibration always much longer in thoſe common Clocks; than in *theſe* conſtructed with the *dead-beat*? And

Recoiling pallets ſhorter, &c.

271. *Are not the pallets always much longer with the dead-beat* than *the recoil*? all which, ARTICLES OF THE GREATEST IMPORTANCE, have

hitherto (it would appear) been *accidental concomitants* of the recoiling pallets ; and every advantage ariſing from THEM, been imputed to the recoil? whereas, all the imperfections ariſing from a *contrary practice* have as erroneouſly being imputed to the *dead-beat*. Thus it appears ; *that*,

In what caſes the advantages of the dead-beat will become evident.

272. No comparative trial can be deciſive, *unleſs where the maintaining power*, *length of Vibration and pallets*, are equal in each Clock *: in which caſe, the ſuperiority of the *dead-beat*, will become evident : *And*

273. If the greater number, and moſt eminent of the profeſſion, have uſed longer pallets with the DEAD-BEAT, than the RECOIL, they can beſt aſſign reaſons for ſo doing ; for none occur to me : nor does, the propriety of imitating precedents, in which neither theory nor practice ſeem to promiſe any real improvement.

274. FROM ALL THAT HAS BEEN SAID relative to PALLETS, the following general rules may be collected.

RECAPITULATION.

That *the recoil in pallets*, *increaſes the effect of any change that may happen in the maintaining power* ; *whether friction and the influence of the oil*, DO ; *or* DO NOT ; *take place* (238).

That *this effect*, *always increaſes as twice the recoil* (238).

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* As repreſented in Plate 3. Fig 2.

Dead-beat.

That *the friction and influences of the oil, do alſo increaſe* (cæt. par.) *as twice the recoil* (178); *and conſequently,*

Compared with the recoil.

That *it is advantageous in all caſes to diminiſh the recoil as much as poſſible.*

That *the dead-beat diminiſhes the alteration that would naturally happen in the time of Vibration of a detached Pendulum, from any change in the length of ſuch Vibration* (262).

That *the influence of the oil and friction, is always leſs on the dead-beat, than on the recoil; all other circumſtances being alike* (181).

That *the recoil can have no tendency to keep the Vibrations of more equal length* (237). Therefore,

That *in all caſes whatſoever, the* DEAD-BEAT *is preferable to the* RECOIL; And that

The uſe of ſprings in pallets, tend to vary the maintaining power (246); *and alſo, have the effect of* A RECOIL (247); *and therefore, never to be admitted.*

275. Having thus ſhewn; *that the dead-beat diminiſhes the natural effect* of any change in the length of Vibration; *when neither friction*, nor *the influence of oil take place during the time of reſt:* I now come to ſhew the manner of conſtructing pallets, wherein *the* PRACTICE *will agree with the* THEORY: and as a ſuperficial view of thoſe matters, may leave ſome doubt, whether a diminution of friction on the pallets, may not be hurtful

PALLETS IMPROVED.

hurtful to the performance: that matter ſhall be conſidered in the notes*.

New Pallets.

276. Plate 4. repreſents the conſtruction of ſuch pallets; Fig. 1. is a front view of the pallets and the *ſwing wheel:* the pallets A, B, C, have their planes of action, conſtructed as in common pallets: (See Plates 2d and 3d); they are ſcrewed to a hollow braſs cylinder O P, which ſerves as a *verge* or axis, and moves on two ſmall pivots as common verges do: to one end of the cylinder, is ſcrewed, the crutch F, Fig. 2. by means of which, the pallets A and C, communicate motion to the Pendulum.

PLATE IV. FIG. 2.

277. d d

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* There are two means, by which the length of Vibration in Clocks may be altered, independent of the denſity of the air: and the effect which the friction on the pallets will have on the performance, will in ſome meaſure depend, on which cauſe, affects.

Firſt, The length of Vibration may be altered in Clocks, by altering the weight that maintains the motion; and in this caſe, the friction (or total reſiſtance) on the pallets, *c. p.* increaſes, as the angle of Vibration: on which account the length of Vibration, will not bear ſo great a proportion to the weight applied, as if no ſuch friction took place. But admitting, that the friction, in ſuch caſe, does diminiſh the effect of any alteration in the maintaining power: as an alteration of the above kind, can never happen by accident: and as every ſuch increaſe of the maintaining power, muſt be made with intent to enlarge the Vibration; it follows: that the friction on the pallets muſt, in ſuch caſe, be hurtful, as tending to diminiſh the *deſired effect.*

Secondly, admitting the weight that is applied to a Clock, to remain invariably the ſame, its effect in lengthening the Vibration, will be increaſed or diminiſhed according to the fluidity, &c. of the oil; which is conſtantly fluctuating, according to the de-

PALLETS IMPROVED.

Detents.

277. d d and e e, are detents, that move *concentric to the braſs cylinder*, on ſmall axles *within the cavity thereof*, (See Fig. 2.) and ſuſpend the Wheel ſo as to allow the Pendulum to move without friction, or influence of the oil, on either pallets or pivots during the whole time of reſt.

Their operation.

278. *Thus*; when the tooth i, eſcapes the pallet A, the tooth k, drops on the detent e, and is ſuſpended,

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gree of heat and cold to which it is expoſed. And the effect of the oil applied to the pallets, in lengthening and ſhortening the Vibrations, has already been ſhewn to bear, to that, on all the pivots, at a mean; the proportion of 80, to 1, (176). Therefore it appears; that in this caſe, by removing the friction, and the influences of the oil on the pallets, we diminiſh the alterations that are ſo frequently occaſioned in the length of Vibration, by the influences of heat and cold on the oil, to one eightieth of what they are, where friction takes place: and this becomes the more deſerving of attention, that there ſeems no other means of removing this evil.

It is alſo to be remembered: that as this friction on the pallets diminiſhes the effect of the maintaining power, in enlarging the Vibration (whether long or ſhort) it muſt, on that account alſo, be hurtful to the performance (41, 46, 47). Add to this; that it tends to correct ſuch alterations, as happen in the *length* of Vibration, owing to the different denſities of the air, more than it does thoſe ariſing from any other cauſe whatever; and this is hurtful to the meaſure of time, as ſhall be ſhewn hereafter; when the different means, by which any alteration in the denſity of the air do affect the times of Vibration, are conſidered. From each, and all, of the above conſiderations it appears; That the friction on Clock-pallets can in no reſpect mend the performance of Clocks; but on the contrary, does by its unavoidable conſequences, give riſe to ſome of the greateſt cauſes of error, that take place in Clocks; and thoſe, incurable by any other means than the removal of ſuch friction on the pallets (155).

ſuſpended, while the pallet C, proceeds towards (n) the bottom of the tooth, and returns, (in the direction of the dotted Arc); joins itſelf to the *detent*; diſplaces *it*; *and thus* receives the tooth k on the plane of action; and ſo, maintains the motion of the Pendulum; and when the tooth k has eſcaped the pallet, C, the tooth m, will drop on the detent d, &c. PALLETS IMPROVED.

279. Fig. 2. is a ſection of the hollow cylinder; (along the line g h) and repreſents the pallets, crutch, and axles of the detents. Sections, &c.

280. Fig. 3. a view of part of the cylinder, pallets, and detents *(in the direction of the line* g h, Fig. 1 and 2.) and ſhows how the detents are brought into the ſame plane of action with the pallets. PLATE IV.

281. Fig. 4. ſhows how the planes of action A and C, are ſcrewed to the pallets: the ſmall hole in the ſtalk, ſerves to ſcrew and unſcrew them.

282. Fig. 5. repreſents part of a Wheel that will admit of Vibrations of any length.

283. Fig. 6. Section of ditto at the line, a b: N. B. *In all thoſe figures, the ſame letters refer to the ſame pieces.*

284. The detents ſhould be fitted very cloſely to the pallets, but *the contact ſhould not be very extenſive*, leſt the effects of *coheſive attraction* become ſenſible; And, Attraction to be guarded againſt, &c.

PALLETS IMPROVED.

Magnetiſm.

285. The greateſt care is to be taken, that neither detents nor pallets have any degree of *magnitiſm*. And

286. Thus may the friction and influences of the oil, during the time of reſt of the ſwing wheel, be removed; *without any of the diſadvantages that attend the application of ſprings**.

287. But though *this conſtruction* of *pallets*, does *much enlarge the Vibration*, and diminiſh, the natural effect, which any alteration in the length of Vibration would have on the meaſure of time in a detached Pendulum (263); as well as remove $\frac{10}{40}$ of the influence of the oil on the Clock (174); *it cannot be ſaid totally* to remove, the effect of every imperfection of the movement. Therefore,

More perfect pallets propoſed.

288. I ſhall next deſcribe *a conſtruction* of *pallets*, that not only removes the friction and influences of the oil, during the time of reſt; but alſo during the motion, of the ſwing wheel; *ſo far as they can any how influence the Vibrations*

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* Such pallets I finiſhed in the year 1763, for a Clock which I had the honour of making for the KING; for journalizing all the changes that happen in the height of the Mercury in the Barometer. Which it does in ſuch manner, that a perſon who has not ſeen a Barometer for the whole year, may by inſpecting its Dial, know with the greateſt eaſe and certainty, not only what changes have happened in any particular day of that year; but alſo, every one change that exceeds the 100 of an inch, which happens in the whole year; with the day and hour, as well as, the particular manner in which each, did happen.

of the Pendulum: theſe pallets, do alſo correct all the irregularities of action in *the main ſpring, wheels and pinions*; or *any other irregularity that can poſſibly happen* in the movement, *from any cauſe whatever*: though the cauſes of ſuch irregularities ſhould altogether eſcape the attention of the artificer.

PALLETS IMPROVED.

289. Plate 5. repreſents ſuch a pair of pallets, and the ſwing wheel; where,

PLATE V.

A, B, C, is the wheel,

D E, the pallets,

H I, two ſmall weights that are fixed on the ſame axles with the pallets, one to each;

PLATE VI.

F G, the detents, which are firmly attached to each other, as well as to the crutch; by means of,

P P, a hollow cylinder of braſs, which ſerves as an axis to the detents; and to which they are ſcrewed: as well as; L, the crutch, which only ſerves to unlock the detents.

M, a weight that exactly ballances the detents, and crutch, by means of which, they retain any poſition that is given them; n, o, are pins attached to the *Pendulum*, (See Plate 7.) and by means of which, the balls I and H, do by their gravity, maintain *its* motion.

290. Plate 6. Fig. 1. repreſents theſe pallets &c. in the direction of M L: and alſo anſwers to the above deſcription.

Fig. 2.

Pallets improved.

Fig. 2. a ſection of the hollow cylinder P P, at right angles to its axis; repreſenting the front of the collar to which the detents, or crutch, are ſcrewed.

291. All the other figures of this Plate, repreſent ſeparately, the pieces belonging to thoſe pallets; and are lettered the ſame, as in the foregoing deſcription; except W W the axles of the pallets; And

292. Z, a ſection of thoſe pieces that are fitted into the ends of the braſs cylinder, and in which the pivots of the axles W W move; the ſmall hole that is next the pivot ſerves occaſionally to take this piece, out of the cylinder (into which it muſt be very truly fitted;) the other two holes are for pinning it, in its place; the ſmall pieces D, F, G, E, (under Fig. 2. Plate 6.) are ſide views of the lower ends of the pallets and detents that are marked with the ſame letters.

293. Plate 7. Fig. 1. is a front view, of the wheel, pallets, detents, and upper parts of the Pendulum; the parts of which that have been deſcribed in the former Plates, are here marked with the ſame letters, nor do the pallets repreſented in this Plate, differ from thoſe in Plates 5 and 6. in any other reſpect, than that in thoſe, the pallets are placed over the wheel; and in theſe under it.

294. Fig. 2. Plate 7. is a ſide view of Fig. 1. where, V's, repreſent part of the Clock-frame, S's

upper part of the Pendulum ; to the lower end of which, the other part is attached by means of a ſcrew, in ſuch manner that each of the ſprings T T, ſhall bear half its weight.—Q, R, are two ſcrews that move with the Pendulum, and by means of which, the detents F and G are alternately unlocked when the Pendulum comes to the extremity of its Vibration.

The Operation of thoſe Pallets.

295. Let us firſt conceive the Pendulum at reſt; and that the pallets, detents, crutch, and pins n, o, remain in the poſitions in which they are repreſented in Plates 5. and 7.

Their operation.

296. If the Pendulum be moved towards the detent F, Plate 7. the pin, n, will riſe towards the arm that ſupports the little weight H ; and the ſcrew R, muſt be ſo adjuſted, that it will unlock the detent F ; and allow the Wheel to advance at the ſame inſtant that the pin, n, feels the weight H : in which caſe, the pallet D, will be diſengaged from the tooth A, and the weight H allowed to deſcend with, and preſs upon the pin, n ; and by this means, maintain the motion of the Pendulum.

297. No ſooner does the Pendulum begin its motion toward F, than the pin, o, is relieved from the weight I ; for the pallet E, reſts againſt the tooth, C, and prevents the further deſcent of I ;

PALLETS IMPROVED.

and thus, the action of the pallet E on the *wheel*, diminiſhes *its* preſſure on the detent F, ſo as to allow it *unlock with the greater eaſe*, which done; the *wheel* advances, and by *its* action on the pallet E, continues to raiſe the weight I till the detent G ſtops *its* motion.

PLATE VII.

298. And, when the tooth C, comes to reſt on the detent G, the weight I, will remain *at reſt* till the Pendulum comes to the extremity of its Vibration towards G; when the pin o, will feel the weight I, and the ſcrew Q unlock the detent G, and allow the ſmall weight I, to deſcend with, and preſs upon the pin o, and by that means, promote the deſcent of the Pendulum; mean time that the wheel raiſes the weight H, for promoting the following deſcent.

Motion maintain'd by the natural action of gravity.

299. Thus are the Vibrations of the Pendulum conſtantly maintained, by the alternate deſcent of the little weights H and I; and *ſince thoſe weights, begin each deſcent from abſolute reſt* (298); it follows; that the power, or velocity with which they are raiſed, *can by no means influence the effect of their deſcent*; And therefore,

No irregularity of action in the movement can influence the Pendulum.

300. However great the irregularities of action, *in the main ſpring*, *wheels and pinions*, &c. *whether ariſing from the influences of heat and cold on the metals*, *oil*, *or friction*, &c. if there remain power, ſufficient to raiſe the weights H and I; *the maintaining power of the Pendulum, will be as invariable as the natural action of gra-*

PALLETS IMPROVED.

vity: and by that means, all the effects of any imperfection in the movement, of whatever kind, are totally avoided *.

The practice equals the theory.

301. Nor does any part of the conſtruction of thoſe pallets tend to diminiſh the advantages thus acquired; *which muſt be the caſe wherever ſprings are uſed* (274).

Obſervation relative to the ſmall weights.

302. Though I have hitherto repreſented the weights H and I, as ſmall balls ſupported by ſlender arms; I here take notice, that they ſhould be made of bars of ſteel, of the ſame ſhape and dimenſions with the Pendulum rod; that heat, and cold, may equally affect them, and that the ſame proviſion may remove their influence in both.

The only imperfection, in thoſe pallets, can have no ſenſible effect on the meaſure of time.

303. The only article that ſeems wanting of *Mathematical accuracy* in thoſe pallets, is, that any change in the action of the wheels may tend to alter the friction on the detents; but if the ſame precautions are here uſed, as in common Clocks, having pinions of eight; and the face of the detents be made of hardened ſteel or dia-

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* Since the Arc of Vibration increaſes, till the reſiſtance of the medium is in each Vibration equal to the maintaining power (259): it follows; that *with an uniform maintaining power*, Vibrations performed in a medium of uniform denſity, would be invariably of the ſame length; in a medium of fluctuating denſity, the lengths of the Vibration bear an inverſe proportion to ſuch denſity: and that, *in either caſe*; the *total reſiſtance* of the medium to the Pendulum will remain uniformly the ſame.

PALLETS IMPROVED.

mond, and the teeth of the wheel of tempered ſteel; any effect that can ariſe from this cauſe, can by no means become perceptible either in the length of Vibration, or meaſure of time (297). But,

304. I avoid ſaying too much in defence of an article that *candour will ſcarce call in queſtion*; and deſpiſe the attacks of prejudice, where I have it in my power to give experimental proof of my aſſertions *: but he who produces a more perfect conſtruction of pallets, is fully intitled to find fault with this; nor ſhall I be backward in making my publick acknowledgments to him who at once points out *the diſeaſe* and *its cure*, in any part of this theory.

Farther uſe of this conſtruction.

305. It is further to be obſerved, that by means of the ſcrews Q and R, the alterations that any change in the denſity of the air will

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* It is extremely eaſy to know the effect that any accidental alteration in the action of the wheels, could have on the meaſure of time; with ſuch pallets: for if the maintaining power be deſignedly altered $\frac{1}{2}$, $\frac{1}{5}$, $\frac{1}{10}$, or $\frac{1}{20}$, ſuch *alteration* will produce the ſame effect, as if it had been accidental; and as it may be continued for any given time, and its whole effect be accurately obſerved, we may with great certainty from ſuch effect (if it becomes ſenſible) eſtimate the effects of ſuch ſmaller changes as may probably happen in the preſſure of the wheel on the detents, by the influences of the oil on the pivots.—The reſiſtance which ſuch friction makes to the Pendulum, in unlocking the detents, may be reduced to any degree at pleaſure, by rendering the ball M ſo much lighter than the crutch and detents, that their exceſs of weight may be made to co-operate, in any degree with the Pendulum, in unlocking the Wheel.

produce in the length of Vibration may be accurately aſcertained.

PALLETS IMPROVED.

306. I make no farther attempt to improve the theory of CLOCK-MOVEMENTS; but now proceed to enquire *how far the advantages already acquired may yet be loſt*; and *what are the moſt effectual means of preſerving them.*

307. THE THREE FOLLOWING cauſes may yet tend to alter the true times of Vibration in Clock-pendulums.

First, *Any change in the elaſticity, or weight of the body to which the Pendulum is ſuſpended.*

Secondly, *The influences of heat and cold on the Pendulum-rod.* And,

Thirdly, *Any alteration in the action of gravity.*

308. As thoſe cauſes tend to alter the times of Vibration, independent of any imperfection in the movement; they ſhall be conſidered ſeparately, *and in the above order.*

SUSPENSION.

309. When the CENTER OF MOTION, or POINT OF SUSPENSION of *a Pendulum*, is conſidered as a fixed point; *its* center of gravity will deſcribe a true Arc of a circle, whoſe radius is, the diſtance of the center of gravity from the point of ſuſpenſion.

310. But if the point of ſuſpenſion be any how at liberty to change its place, the times of Vibration will thereby be altered.

311. Example.

PLATE VIII.

311. **Example. PLATE VIII.** If a pendulous body B, vibrate round an *immoveable point* A, its center of gravity will deſcribe a *perfect Arc of a circle* as B B B, whoſe radius is A B; but if the point of ſuſpenſion moves at each Vibration, ſuppoſe from A, to a, on either ſide; the center of gravity will deſcribe a different curve, as C B C, which may here, for the ſake of illuſtration, be conſidered as a true circular Arc: let the center of this Arc be found *thus*; round the point B deſcribe any circle, and alſo round the points C, C, deſcribe Arcs cutting the ſaid circle any where, as at the pivots e, e, e, e, and, through thoſe points of interſection, draw lines towards A, and they will paſs through the points a, a, and meet in D, which will be the center of the Arc C B C; and conſequently the times of Vibration in the Arc C B C, will be the ſame, as if D B, was the length of the Pendulum, and the point of ſuſpenſion immoveable.

Motion of it, worſe than a change of length of the Pendulum.

312. And *thus it appears*, that any motion of the point of ſuſpenſion, will alter the times of Vibration, *more than* an equal change in the length of the Pendulum would do; *in the proportion of* A D, to a a.

Wood; why improper for it.

313. All ſorts of wood attract and imbibe moiſture, and by this means alter their degree of elaſticity; and conſequently, if a Pendulum

be ſuſpended thereto, the motion of its point of ſuſpenſion, will vary with the elaſticity of the wood; and the times of Vibration will alſo be altered (312); and this effect, will always be conſiderable in the meaſure of time, wherever the Pendulum is ſuſpended in the common manner, or is any how dependent on the *caſe*; for *its* elaſticity is liable to change by every change in the moiſture, &c. of the air. OF THE SUSPENSION, &c.

314. The changes that happen in the weight of the caſe, will alſo concur with the former, in altering the times of Vibration: for it is certain, that in moſt Clocks, the caſe, &c. are moved by the Pendulum at each Vibration; and it is no leſs certain, that the ſame power will move a lighter body (*cæt. par.*) further than a heavier; *therefore*, the heavier the *Clock-caſe*, the ſhorter ſpace will the Pendulum move *it*; and *thus*, *will any change* in *the weight*, as well as *elaſticity* of *the caſe*, alter *the motion of the point of ſuſpenſion*, and conſequently the times of Vibration (312)*. Further reaſons.

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* Were it neceſſary to ſatisfy the reader, that the caſe and Clock are generally moved by the Vibrations of the Pendulum, I would recommend to him the uſe of a ſmall pamphlet, by Mr. *John Ellicott*, intituled; An account of the influence, which two Pendulum Clocks were obſerved to have upon each other, *&c.* And of Hugens's Horologium Oſc. pages 18 & 19. in each of which he will meet with inconteſtible proofs, that the point of ſuſpenſion is not fixed, but moves with the Pendulum.

315. What

OF THE SUSPENSION, &c.

Brick and freeſtone, liable to ſome objections.

Lead, or marble beſt.

315. What is above ſaid of wood, is applicable in a leſs degree to brick, freeſtone, or any ſubſtance that imbibes moiſture: and for this reaſon; LEAD, and MARBLE *ſeem the fitteſt ſubſtances for ſuſpending Clock-pendulums to:* and to render ſuch ſuſpenſion perfect; a block of either, of at leaſt 4 or 500 weight, ſhould be built as compactly as poſſible in a wall, and the Pendulum ſuſpended near its middle; for by this means, the point of ſuſpenſion would be rendered much more immoveable, and the times of Vibration *more iſochronal* (312).

PENDULUM RODS.

The influences of HEAT *and* COLD *on the* PENDULUM ROD *comes next in courſe* (308).

319. In all that has been hitherto ſaid, the length of the Pendulum has been conſidered as invariably the ſame, *but the contrary happens in practice:* for *heat dilates*, and *cold contracts* all metals; by which means, *the ſame Pendulum is longer in ſummer than in winter.*

317. Various expedients have been thought of for correcting this imperfection; all of which that occur to me, *except one*, depend on the oppoſition of expanſion, to expanſion; in ſuch manner, that the one ſhould ſhorten the Pendulum as much as the other lengthened it: and the contrary.

Wooden Pendulum rods.

318. The *only method* that does not depend upon the above principle, is by making the Pendulum rod of the ſtraighteſt grained wood; *the*

longitudinal expanſion of which is ſo very ſmall, that it anſwers ſufficiently for ordinary purpoſes, and is equal to any *other*, *in Clocks wherein the influences of the oil take place on the pallets* (193, 195) *.

INFLUENCE OF HEAT AND COLD ON THE PENDULUM ROD.

319. All the ways that have been, or can be uſed, *for applying the expanſion of metals*, may be reduced to two general CLASSES; namely,

Thermometers all reducible to two CLASSES.

320. Such as DO; or DO NOT; *move with the Pendulum.*

Namely,

321. Thoſe that *do not* move with the Pendulum, are either attached to the frame, or caſe of the Clock; and ſo conſtrued as to raiſe the Pendulum-ſpring betwixt two cheeks juſt as much as the whole rod is lengthened; and the contrary; by which means, the diſtance of thoſe

Of thoſe that do not move, &c.

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* If I was to adopt any principle or contrivance, on the reputation of its inventor, it would be this; it being invented, and often applied with good ſucceſs, by my late Noble Patron ARCHIBALD DUKE OF ARGYLL, whoſe ſuperior abilities and penetration, might with many, juſtify a conduct in direct oppoſition to thoſe rules which HE conſtantly obſerved in philoſophical enquiries: and if the fulleſt conviction of His abilities; joined to the moſt grateful ſenſe of that goodneſs, to which, (under Providence) I may juſtly be ſaid, in the firſt place, to owe every bleſſing which I do, or can enjoy; are not arguments ſufficient, for adopting without further inquiry or experiment, a contrivance worthy of the greateſt philoſopher of his age: ſurely none other have reaſon to imagine that any indignity is meant, when the merits of their inventions are minutely examined.

cheeks from the center of oſcillation, is always preſerved the ſame.

Inconvenience.

322. Here it is to be obſerved, that as the ſpring is to move freely up and down, between thoſe cheeks, it is apt to have ſome ſhake in its Vibration, which is no deſireable circumſtance where great accuracy is required.

Ditto.

323. Secondly, That every change in the temperature of the air, that influences this Thermometer; alſo alters the length of that part of the Pendulum-ſpring that acts in the Vibration: conſequently its ſtiffneſs will be altered, which will vary the time of Vibration (137).

Ditto.

324. Thirdly, Since this Thermometer remains in its place *without motion*, any change that happens in the temperature of the air, will not affect it, *ſo ſoon* as the Pendulum rod; which is in conſtant motion, and by that means, making continual approaches to particles of air, whoſe temperature have undergone no change from their former propinquity to it; or if they have, again recover the ſame temperature, before the return of the Pendulum rod: *and thus it appears*,

Immoveable thermometers too ſlow in their effect.

325. That *any Thermometer that is immoveable, can never be ſo ſoon influenced by the changes of heat and cold*, as *the Pendulum rod:* and therefore the evil muſt take place for ſome time, before the remedy is applied; this is univerſally true of all the Thermometers *of this claſs* (321).

326. *How*

ON THE PENDULUM ROD.

326. *How different is the caſe in the* MERCURIAL PENDULUM? for as the *cylinder* of *Mercury* moves quicker through the air, than the *mean motion* of the Pendulum rod, IT *will be ſooner heated and cooled* by the air, *than the Pendulum rod*; and if we add to this, that no body in nature of the ſame denſity is ſooner heated and cooled than Mercury; it will appear that this Mercurial Thermometer, is as much too quick, as the other is too ſlow: and conſequently, (Mercurial Pendulums too quick, &c.)

327. That *neither the Mercurial Pendulum,* (326) *nor any Thermometer that does not move with the Pendulum* (325), can have a perfect effect. (And neither, can ever be rendered perfect.)

328. *From what has been ſaid* it appears, that in order to make a Thermometer perform properly, it ſhould be made of the ſame metal with the Pendulum rod (326). (Properties neceſſary to all thermometers.)

329. *Secondly,* It ſhould conſiſt of bars of the ſame exact dimenſions with the Pendulum rod; and each of its parts, ſhould in every reſpect have the ſame expoſure to the air with the correſponding part of the Pendulum rod. (Ditto.)

330. *And laſtly,* Each part of the Thermometer ſhould be extended, or compreſſed, with the very ſame degree of power with which the correſponding part of the Pendulum rod is extended or compreſſed: *nor can any Thermometer ever perform to the utmoſt exactneſs of which their nature admits,* without very particular re- (Ditto.)

gard

gard is paid to each of the above articles, (328 to 331).

The gridiron and Mr. Ellicott's beſt, on thoſe accounts.

331. *The* GRIDIRON *Pendulum*, and Mr. ELLICOTT's, correſpond with thoſe particulars more fully, than any other conſtruction with which I have met; *on which account*, I ſhall attempt a more particular examination of them; and to the beſt of my judgment, point out the advantages and imperfections of each: ſo far as it can tend to improvement.

Of the Gridiron Pendulum *.

Its general principles.

332. The expanſion of braſs, is always allowed to exceed that of ſteel, generally in the proportion of 5 to 3; on which ſuppoſition, if any piece of ſteel by the application of a certain degree of heat, expands $\frac{3}{10}$ of an inch: a piece of braſs of the ſame length will, with the ſame heat, expand $\frac{5}{10}$ of an inch; and, ſince the whole length of braſs expands $\frac{5}{10}$ and the expanſion *through the whole* is ſuppoſed uniform; if it be divided into five equal parts, each part, will have

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* It may ſeem unneceſſary here to ſay, that Mr. John Harriſon is generally reputed the inventor of this ingenious contrivance; and that, if Mr. Ellicott's name is oftener mentioned, in deſcribing the following invention, than Mr. Harriſon's, in this; it proceeds from no partiality: but becauſe Mr. Ellicott's invention is known only by his name.

expanded $\frac{1}{10}$ of an inch; therefore if we take away $\frac{2}{5}$ of its whole length, the expanſion of the remaining $\frac{3}{5}$ will be $\frac{3}{10}$ of an inch: but the expanſion of the whole bar of ſteel, is alſo $\frac{3}{10}$ of an inch (by the hypotheſis), *therefore*, the expanſion of a bar of ſteel, is equal to the expanſion of a bar of braſs of $\frac{3}{5}$ its length. *And univerſally,*

Proportion of the braſs and ſteel wires.

333. When the length of the bars, is *inverſely* as the expanſion of the relative metals; the whole expanſion in each bar, will be equal: and conſequently may be applied to ballance each other; this being the foundation of the *gridiron*. I now come to *the application*

PLATE IX. FIG. 1.

334. Let A B Fig. 1. Plate 9. repreſent the length of any given Pendulum to which a *gridiron* is to be applied; biſect A B, in C, and make B D, D E and E F, each equal to A C or C B, then, A F, will be to B F, (that is, H G,) as 5 to 3; therefore (332) if A F be ſteel, and H G, braſs, their expanſions and contractions with any degree of heat and cold will be equal: and if G H, be firmly attached to A F at their extremity F G; and A F be ſuſpended by the point A; A F, will expand upwards, as much as G H, does downwards; and the points A and H will always keep the ſame diſtance from each other; *conſequently*;

335. *If a Pendulum be conſtructed whoſe point of ſuſpenſion is* A, *and its center of oſcillation* H, *it can neither be lengthened nor ſhortened, by any change of heat and cold*; And, thus

The bars may be cut into any convenient lengths.

336. It appears (334), that whatever be the length of a Pendulum; three half lengths of ſteel, and as much of braſs, muſt be added, in order to have as much expanſion upwards as downwards: *and when the whole length of bars* is *thus aſcertained*, they may be cut into ſuch ſeveral lengths as may beſt ſuit the purpoſe, and evade the inconveniencies of having any part of them below the ball of the Pendulum *:

The braſs to expand upwards, &c.

337. Always obſerving, *that the expanſion of the ſteel tend downwards*, and *that of the braſs upwards*; in which caſe, they will ballance each other, without regard to the number of pieces into which they are cut; for the effect of the whole, conſiſts of the effects of all its parts: Therefore,

PLATE IX. Illuſtration.

338. If the ſteel bar A F, Plate IX. Fig. 1. be cut into three unequal lengths, and the braſs

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[*] Here it is to be obſerved, that the ſcrew by which the length of the Pendulum is adjuſted; ſhould act as near as poſſible to the center of *gravity* of the ball: by which means any expanſion of the ball can no ways alter the diſtance of the center of oſcillation from the point of ſuſpenſion: and this may be effected by means of a long ſocket attached to the nut at the bottom of the Pendulum, and paſſing up through the ball, to its center of gravity; WHERE, it muſt act on the ſcrew, and ſupport the ball.

bar

On the Pendulum rod.

bar H G into two; and thoſe five pieces be applied and connected with each other, as in Fig. 2. *the braſs will expand upwards* as much as *the ſteel does dowards*, and the center of oſcillation B, always keep the ſame diſtance from A, the point of ſuſpenſion; nor will the expanſion of the little croſs pieces that connect the bars, be of any effect, it acting laterally only.

Why more wires neceſſary in practice than in theory.

339. *Though in theory five bars only*, are neceſſary for conſtructing a gridiron (338); *nine are requiſite in practice*; in order that the bar to which the Pendulum is immediately ſuſpended, be equally ſupported on each ſide: to prevent ſuch tremulous motion or bending of the bars, as might otherwiſe take place; See Fig. 3. where it appears by inſpection that the correſponding bars on either ſides the center, co-operate in ſuch manner, as to move both ends of the croſs bars equally, and by that means, prevent ſuch bending of the upright ones, as muſt otherwiſe happen by the weight of the ball B; nor do thoſe additional bars, *thus applied*, any how increaſe the expanſion.

PLATE IX.

Drawing at full ſize.

340. Fig. 4. repreſents the manner of connecting the bars in a *gridiron*; and is drawn of the ſize commonly uſed for royal Pendulums; the bars could not be repreſented here at full length, and are therefore broke in the middle; the letters with which the round bars are marked ſerve to denote the metal of which each is made;

and that part of the middle rod which is above the piece E, ſerves only for keeping the three bars on each ſide thereof, in the ſame plane with the two outſide ones ; it alſo anſwers a like purpoſe at the lower end of the gridiron, *and is pin'd in the croſs piece* E, *only* ; and moves freely, *but without ſhake*, in the pieces C, D, F and G.

Two ſprings beſt.

341. I have always prefered the ſuſpenſion by two ſprings, to that with one ; and have here repreſented, *the piece to which the ſprings are attached*, together with the piece C, to which *it* is ſcrewed, *in ſeveral different views* ; all the other croſs pieces, are alſo repreſented ſeparately, and marked with the ſame letters as in the Pendulum.

Croſs bars.

342. The upright bars, or wires, are generally connected towards the middle by one or more croſs pieces, that ſerve ſtill further to prevent any tremulation that might ariſe from their elaſtic flexibility ; thoſe pieces are pin'd to the two extreme bars, and allow the other ſeven to move freely, yet without ſhake, in their holes.

How the gridiron is adjuſted.

343. In all that has been hitherto ſaid, *the expanſion of braſs has been ſuppoſed to bear to that of ſteel, the exact proportion of five to three* ; and *that all dimenſions have been accurately laid down agreeable thereto* ; but, leſt on trial, the contrary ſhould appear, the gridiron may be adjuſted, by ſhifting the croſs piece F, upwards or downwards, for which purpoſe, ſeveral holes

are made in the upright rod, that correſpond exactly with thoſe in the piece F. See Fig. 4.

Round wires better than ſquare, even in theory.

344. It is further to be obſerved in conſtructing gridirons; *that round wires* are much preferable to ſquare bars, *even in theory*, and independent of all practical advantages; as there is a more *equal* and *free* admiſſion of air to each wire; in order to promote which, *the wires ſhould never ſtand cloſe to each other*; and thus it appears:

And hollow cylinders, worſe than ſquare bars.

345. THAT *gridirons compoſed of ſquare bars*, cloſely fitted to each other, do in ſome degree *partake of the inconvenience of immoveable Thermometers* (325); though not to ſuch a degree, *as where hollow cylinders are uſed*.

I NOW COME to the theory of Mr. ELLICOTT'S PENDULUM, *the deſcription, &c. of which are here given in his own words.*

Mr. Ellicott's Pendulum deſcribed.

PLATE X. FIG. 1.

346. "Plate 10. Fig. 1. repreſents the Pendulum: in which a b, is a bar of braſs made quite faſt at the upper end by pins, and held contiguous at ſeveral equal diſtances, by the ſcrews 1, 2, &c. to the rod of the Pendulum, which is a bar of iron; and ſo far as the braſs bar reaches, is filed of the ſame ſize and ſhape, and conſequently does not appear in the figure; but a little below the end of the braſs bar, the iron is left broader, as at d d, for the conveniency of fixing the work to it, and is made of a ſufficient

length

INFLUENCE OF HEAT AND COLD

Mr. Ellicott's Pendulum deſcribed.

length to paſs quite through the ball of the Pendulum to c. The holes 1, 2, &c. in the braſs, through which the ſhanks of the ſcrews paſs into the iron rod of the Pendulum, are filed as in the drawing, of a ſufficient length to ſuffer the braſs to contract and dilate freely by heat and cold, under the heads of the ſcrews; e e e e, repreſent the ball of the Pendulum; f f, two ſtrong pieces of ſteel, or levers, whoſe inner centers, or pivots, turn in two holes drilled in the broad part of the Pendulum rod, and their outer ones in a ſtrong bridge, or cock, ſcrewed upon the ſame part of the rod, but omitted in the draught, becauſe when put on, it covers this mechaniſm; g g are two ſcrews entering at the edge, and reaching into the cavity near the center of the ball. The ends of the ſcrews next the center, are turned into the form repreſented in the drawing, which, preſſing with the weight of the ball againſt the longer arms of the levers, cauſe the ſhort ends to preſs againſt the braſs bar at b. Things being in this ſituation, let us ſuppoſe, that the rod of the Pendulum, and the braſs annexed to it, grow longer by heat, and that the braſs lengthens more than the iron of the ſame length; then the braſs by its exceſs of dilation, will preſs the ſhort ends of the levers downwards at b, and at the ſame time neceſſarily lift up the ball, which reſts on the long ends of the ſame levers at f f, to any proportion neceſſary: and provided the ends of the ſcrews do preſs upon the levers at a proper diſtance from the centers, the ſaid ball will be always kept at the ſame diſtance from the point of ſuſpenſion, notwithſtanding any alteration the rod of the Pendulum may be liable to from heat or cold. What this diſtance ought to be, may very nearly be determined, if the difference of expanſion between the iron and braſs bars is known; for the proportion the ſhorter arms of the levers ought to bear to the longer ones, will always be as the exceſs of expanſion of the braſs is to the whole expanſion of the iron, as may be thus eaſily demonſtrated."

ON THE PENDULUM ROD.

Mr. Ellicott's Pendulum deſcribed.

PLATE X.
FIG. 2.

Plate 10. Fig. 2. "Let the line a b, drawn perpendicular to the line e f, repreſent a bar of iron; the line e d, a bar of braſs; the pricked line b g, the expanſion of the iron bar by any particular degree of heat; the pricked line d h, the expanſion of the braſs bar by the ſame degree of heat; let the line g i, be drawn parallel to the line e f; then will i h, repreſent the difference of the expanſion of the two metals: through the points h, g, draw a right line cutting the line e f, as in k; this line may be ſuppoſed to repreſent one of the levers turning upon its center at g; h the point where the braſs bar acts on the ſhorter end of the lever, and k, the point where the ſcrew acts upon the longer end of the lever, which being the place where it interſects the line e f, it is evident the ball of the

Mr. Ellicott's Pendulum deſcribed.

Pendulum will be as much raiſed by the lever, as it would have been depreſſed by the expanſion of the iron; but the triangle i h g, is ſimilar to the triangle b g k; and therefore, as i h, the exceſs of the expanſion of the braſs, is to b g, the whole expanſion of the iron, ſo will h g, the ſhorter arm of the lever, be to g k, the longer arm of the lever, Q. e. d."

PLATE X.

"At c, Fig. 1. is placed a ſtrong double ſpring, whoſe ends preſſing againſt the under edge of the ball, hinder it from bending the braſs bar by its forcible motion thereon, at the point b, which, when the ball is of a conſiderable weight it might otherwiſe be very liable to do. The deſcription here given is exactly agreeable to the original contrivance: and the only alteration I have ſince made in it, conſiſts in placing the ſcrews g g, within the ball of the Pendulum."

Characteriſtick of true demonſtrations.

347. *I ſhall not attempt any further explanation of the above contrivance*, which its author has deſcribed in a very clear and diſtinct manner; nor does any error appear to me in his demonſtration, *if the ſuppoſitions on which it is partly founded are allowed*; but it is neceſſary, *not only*, that all mathematical demonſtrations, be founded on data that are ſtrictly true; *but alſo*, that they comprehend every circumſtance that can any how affect the reſult; *in which caſe only*, the theory and practice can agree.

ON THE PENDULUM ROD.

Mr. Ellicott's Pendulum examined.

348. It is obvious, that the above demonſtration *ſuppoſes the Pendulum rod perfectly inflexible*, and *that all the parts move without friction*; in which caſe, the operation muſt be perfectly ſmooth and uniform: *But*

Objection.

349. If the Pendulum rod be in any degree flexible, and friction take place in any part of the contrivance, the operation cannot be perfectly ſmooth, and the irregularity of the motion, will increaſe with the friction and flexibility of the rod. Example,

Illuſtration.

350. If two rods of different metals be firmly attached to each other at one end, but at liberty to move freely and without reſiſtance on each other, *towards the other end*, they will expand and contract uniformly and without the leaſt tendency to bend: as in Plate 11. Fig. 1.

PLATE XI.
FIG. 1.

351. But if thoſe rods be connected with each other, *not only at their extremities*, but alſo *at ſeveral intermediate ſpaces*; and have different expanſions, they will form themſelves into a circular Arc, as in Fig. 2. Plate 11: and the reſiſtance which thoſe elaſtic rods make to the bending, *increaſes as the ſpaces to which they are bent*. Therefore,

352. If ſuch rods be firmly attached to each other, *at one end only*; and *by a limited power at the other*; they will, on any change of heat or cold, continue to bend, till the ſtiffneſs of the rods (351) does ſomewhat *exceed the uniform limited power*

Mr. Ellicott's Pendulum examined.

power with which they are connected; at which period, the rods will ſuddenly ſlip on each other and become ſtraight; this limited power being no longer able to ballance the reſiſtance of the rods: and *thus* will *they bend*, and *move* alternately, by means of the changes of heat or cold; and the ſpaces to which they bend, will always depend on the proportion which the limited power that connects the *rods*, bears to *their* ſtiffneſs.

PLATE XI.

Jerks rendered more minute and frequent.

353. Let two ſuch rods be ſuſpended, at one end, and a weight applied to the other, as in Fig. 3. Plate 11. And *this weight*, *as well as the ſtiffneſs of the rods*, will tend to oppoſe *their* bending, and the oppoſition which *it* makes, *increaſes as the verſed ſine of the Arc into which the rods or bars are bent* (See the dotted lines in the Fig.) and the application of this weight will render the bendings *leſs*, and *more frequent*; ſo as more nearly to approach an uniform motion.

Application of the preceding theory.

Double ſpring applied.

354. Now if we conſider *the friction on all the parts* of ſuch a Pendulum as repreſented in Plate 10. as a limited power, that connects the lower ends of the braſs and ſteel bars; (for they can have no relative motion till this friction is overcome) the bending of the rods will *(cæt. par.)* be proportioned to it (352, 353); ſo *that by diminiſhing the friction, the motion is rendered more uniform*; of which, the ingenious inventor, was

ſo well aware, that he judiciouſly applied the double ſpring below the ball.

ON THE PENDULUM ROD.

Mr. Ellicott's Pendulum examined.

Friction cannot be wholly removed by the application of a ſpring.

355. But this ſpring *muſt not ſuſtain the whole weight of the ball*; and therefore, though the friction may be very much diminiſhed, it can never be totally removed by the application of a ſpring; nor can we be abſolutely certain that the ſcrews g g, Plate 10. Fig. 1. bear equally on the levers; if they do not, it muſt incline the ball to one ſide, ſo as to rub at the upper *part*, againſt the bars; which will generate a friction of ſuch a nature as muſt ever be attended with jerks*.

356. Since the friction on the levers is at leaſt *nearly uniform*, and the reſiſtance, which the weight, and ſtiffneſs of the rods make to the bending, is of an *accumulating nature* (352, 353); it follows, that when the rods are ſtraight, the

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* In ſome caſes, friction generates friction; as when a wetted finger is moved forward along a ſmooth table, as repreſented in PLATE X. Fig. 3. it will always move by jerks; but if moved backwards, it ſlips ſmoothly: the caſe will be ſomewhat ſimilar here, if the levers ſhould not bear an equal preſſure from the ſcrews that ſupport the ball.—In a Pendulum which I have now making, with the improvements here propoſed; the ſpring which ſuſtains the ball, is made of a helical form (like theſe in ſmall portable ſtill-yards,) ſo that it moves with the greateſt freedom, and by means of a ſcrew at the bottom of the ball, (within which, is the ſpring): its action may be increaſed or diminiſhed at pleaſure, ſo that the levers ſhall ſuſtain any aſſigned part of the weight. In it, I have alſo ſomewhat altered the manner of adjuſting the levers from that in Mr. Ellicott's; by which means, the length of the Pendulum is leſs liable to be altered, by ſuch adjuſtment.

Mr. Ellicott's Pendulum examined.

Jerks muſt take place while friction remains.

the reſiſtance to the bending totally ceaſes; nor can it be ſuppoſed to take place, before the rods are ſomewhat bent; *nor will the bending ceaſe, till this reſiſtance is ſo much increaſed*, as *to exceed the friction* (354); conſequently while there is a friction, there muſt be a bending, and this bending muſt produce an irregularity in the motion; which, however ſmall, or imperceptible, it may be to our ſight, in any experiment, muſt ſtill render the effect leſs perfect, than if the motion was more uniform; *and therefore*, ſuch a conſtruction as does not admit of a probability of ſuch irregularity of motion is certainly to be preferred *.

Propoſal for remedying the foregoing inconveniences, &c.

357. Having endeavoured to point out the chief inconveniences, that *I imagine* Mr. ELLICOTT's *Pendulum* in its preſent ſtate liable to; I ſhall next endeavour to obviate *them*, or any others that occur to me, ſo as to give IT all thoſe advantages of which the conſtruction ſeems *peculiarly ſuſceptible*: nor have I the leaſt doubt of meeting with His approbation, if I

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* It is probable that any improvement of Mr. Ellicott's Pendulum beyond its preſent ſtate, might anſwer no great end in improving the performance, while the influences of the oil, or any other imperfections of the movement, can tend to diſturb the natural tendency of the Vibration: but when all thoſe evils are removed, theſe merit attention; and the effect of removing them will, I doubt not, then become ſenſible in the performance of theClock.

ON THE PENDULUM ROD.

Mr. Ellicott's Pendulum examined.

ſucceed in the improvement of a contrivance which HE ſo candidly laid before the public; nor do I imagine *that malice itſelf*, *can conſtrue this examination into a breach of friendſhip*, when it is declared that my approbation of the contrivance induced me to it: and if I ſpare not the inventions of thoſe whom the public eſteem; and I always wiſh to reckon among the number of my friends; *it proves*, *that I adhere to my reſolution* of preferring demonſtration to opinion; and that no diſreſpect is meant wherever the one is oppoſed to the other.

Three bars of metal applied, &c.

358. If three bars of metal (one of braſs and two of ſteel) be firmly connected at one end, and held together by any determined power towards the other end; any increaſe of heat will expand the braſs bar more than the ſteel ones; and if it were connected with one of the ſteel bars only, they would be bent, as in Fig. 2. Plate 11. but here, it being connected with a ſteel bar *on each ſide*, they endeavour, by means of the limited power which connects them, to bend it; *each operating its own way*, by which means they counteract and deſtroy each other's effect, ſo that no bending can *in this caſe* take place: but the leaſt change in their expanſions, will alter the relative poſitions at their extremities, and the motion will be uniform and regular, unleſs the reſiſtance be ſo very great, as actually to compreſs or ſtretch the bars, which I am apt to be-

No bending.

lieve, can never be the caſe in a Pendulum that is executed with diſcretion. *Therefore,*

Mr. Ellicott's Pendulum examined.

How the three bars are to be applied, &c.

359. In *Pendulums with levers*, two bars of ſteel and one of braſs ſhould be uſed, as repreſented by Fig. 7. Plate 11. the ſcrews that connect the *bars*, are made to allow the *one of braſs*, to move freely between thoſe of ſteel; and the rods are kept at a ſmall diſtance from each other, ſo as to give *a free admiſſion of the air* to *the braſs bar*, that *it* may be heated and cooled *at the ſame inſtant* with the ſteel *ones*; which muſt have a more perfect effect, than where the braſs is affected by its communication with the ſteel: nor is even this trifling circumſtance unworthy of notice, when we recollect what is ſaid in paragraph (248).

Further cautions.

360. From what is above ſaid (358), it might at firſt ſight be thought, that, with this addition, little or no regard needs be paid to the quantity of friction; or whether the levers bear an equal weight; but let it be obſerved, that though the bending of the bars, is by this means prevented in the direction wherein it naturally takes place in the higheſt degree, an unequal bearing on the levers would tend to bend the bars edgeways; and though ſuch bending muſt be very trifling, even when compared with what has been heretofore conſidered, the effect cannot be hurt, and may be rendered more perfect, by removing as much as in our power, *even the probability* of any jerk or bending, however ſmall.

361. Plate

ON THE PENDULUM ROD.

Mr. Ellicott's Pendulum improved.

361. Plate 11. Fig. 5. repreſents one of the ſteel bars with the *braſs bar* and levers; on which *it* is made to act, (by means of the piece b,) *in ſuch manner, that each ſhall have equal preſſure*, notwithſtanding any inaccuracies of execution, &c.

Improvements.

362. N° 1. (under Fig 5. Plate 11.) repreſents the lower end of the braſs bar, together with the cylinder c, and piece b, each ſeparately; and N° 2, and 3. are different views of the levers.

Remark.

363. Fig. 6. Plate 11. part of one of the ſteel bars, to be ſcrewed to the bars Fig. 5. as repreſented by Fig. 7. the large opening in it, ſerves to ſhew, the ends of the levers with the piece b, &c. From what has been ſaid, it appears, that Mr. Ellicott's *Pendulum*, can no more be rendered perfect, *with two bars*, than *the gridiron can with five* (339); nor can the effect be perfect in any Pendulum with *levers*, where *each* does not bear an equal weight (360); and conſequently, *any Pendulum conſtructed with one lever*, can never have a perfect effect.

In favour of Mr. Ellicott's Pendulum.

364. From what is above ſaid it is not to be underſtood, that this Pendulum in its preſent ſtate, is as imperfect as a gridiron of five bars (339), *though it does in a leſs degree, partake of the ſame inconveniency*: but when three bars are uſed, and the bearing on each lever, rendered equal; the

Of Mr. Ellicott's Pendulum.

the effect of Mr. *Ellicott*'s, will in every reſpect equal that of the gridiron Pendulum; *with the* ſuperior *advantage of being much more eaſily*, and *accurately adjuſted*, than any *gridiron Pendulum* that I have ſeen; not to mention ſome ſmaller advantages (329).

Objection to it.

365. The objection that will moſt probably be yet made to Mr. *Ellicott*'s *Pendulum*, is, that it is *regulated* by raiſing the Pendulum ſpring through a ſlit, &c. by which means the length of the ſpring is altered, in regulating the length of the Pendulum: but, though this is allowed to be an imperfection in the conſtruction of *Clock-thermometers* (323), it is not of equal moment in this caſe; for when the Pendulum is once got to vibrate true time, *the length of its ſpring is no more altered*: beſides it is eaſily to ſubſtitute other methods of regulating, that ſhall in no degree be liable to this objection.

Anſwered.

Further remarks.

366. As to the increaſe of reſiſtance that may take place owing to the cavity in the ball; I ſhall endeavour to ſhew hereafter, how the reſiſtance of the air may be diminiſhed with this, and all other Pendulums, by altering the ſhape of their balls.

Objection to the gridiron.

367. If in the gridiron Pendulum, the *ball* be ſupported by the lower edge, the whole expanſion *thereof* will tend upwards; and its contraction, downwards; nor can the effects of heat or cold, on ſo thick a body, keep pace with

thoſe

ON THE PENDULUM ROD.

those of the Pendulum rod; therefore in this caſe the effect of a gridiron is leſs perfect than Mr. *Ellicott*'s; but this may be corrected by ſupporting the ball, by its center of gravity. ON THE WHOLE,

Of Mr. Ellicott's Pendulum.

Mr. Ellicott's eaſieſt adjuſted, and more perfect, in effect.

368. The only material difference that I can diſcover in the advantages of thoſe ingenious contrivances, in their moſt improved ſtate, is: *That Mr.* ELLICOTT's *is by much the eaſieſt adjuſted* *; and *that*, *when the air has free admiſſion between its bars*, *they are more equally heated and cooled*, *than even thoſe of the* GRIDIRON; in which, *the bars at the extremities*, are ſooner affected by any changes in the temperature of the air, *than thoſe towards the middle*: ſo that the effect muſt be *moſt perfect* where all the bars are *moſt equally* heated and cooled (329).

369. I ſhall now endeavour to bring into one point of view, the ſubſtance of what has been ſaid relative to the influence of heat and cold on Pendulums.

RECAPITULATION.

That *wooden Pendulum rods may anſwer for Clocks wherein the influences of the oil take place on the pallets* (318).

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* Mr. Ellicott's Pendulum may be adjuſted to the greateſt nicety, without ſtopping the Clock many ſeconds, or running ſo great a riſque of altering the former length of the Pendulum, as in all the gridiron Pendulums I ever ſaw.

That, *before the influence of the oil is removed in Clocks, their performance may be hurt, by totally remedying the influences of heat and cold on the Pendulum*, particularly *with recoiling pallets* (195, 196).

That, *no Thermometer that remains immoveable in its place, can perfectly remove the influence of heat and cold on the Pendulum rod* (325).

That, *the Mercurial Pendulum is too ſoon affected by the changes of heat and cold*; and therefore *can never have a perfect effect, in remedying their influences* (326).

That, *the* GRIDIRON, *and* Mr. ELLICOTT's *methods for removing the influences of heat and cold, are the beſt that have yet appeared* (331).

That, *no Pendulum can be conſtructed with one lever, ſo as to have a perfect effect* (363).

That, *the bars are more equally heated and cooled in Mr.* ELLICOTT's *than the* GRIDIRON *Pendulum* (368).

And that, *the former is much more eaſily adjuſted than the* LATTER (368).

Pendulum with levers, preferable.

370. Which two laſt properties, do for general uſe give the preference to the conſtruction with levers. *If I have in this examination committed any overſight or error; the manner which has been obſerved* through the whole, *lays them open to the detection of thoſe who reaſon with more propriety.*

371. Some

ON THE PENDULUM, &c.

371. Some may expect, that the method of determining when ſuch Pendulums are accurately adjuſted, ſhould be here given; but where time admits, a due attention to the performance of the clock, is the beſt means, as it includes every circumſtance that can affect.

CHANGES IN THE ACTION OF GRAVITY.

372. As *to the changes that may happen in the* ACTION of GRAVITY (307); they only take place from a change of latitude, and muſt be corrected in the length of the Pendulum.

Introduction to the changes of denſity in the air.

373. *Having ſhewn above*, how to render the maintaining power *perfectly uniform* (300), the point of ſuſpenſion *immoveable* (315), and the length of the Pendulum *invariable* (316 to 373); ſuch *changes* as happen in the DENSITY *of the air*, ſeem now, the *only remaining cauſe*, that can alter the *length*, *or time* of Vibration.

Enquiry.

374. *I therefore proceed to enquire into*, the comparative effects that ſuch *changes* may have on the times of Vibration performed in *cycloidal* and *circular* Arcs, *when no other cauſe* tends to alter their times.

375. If a Pendulum was made to oſcillate in an exhauſted receiver, free from reſiſtance of any kind, its Vibrations would continue *equal*, and *iſochronal* (14), whether performed in the *cycloidal* or *circular* curve: And,

Abſolute gravity, in what caſe the motive force.

376. And if the action of gravity, on *ſuch Pendulum*, was altered, ſo would its times of Vibration

bration (17); for in this caſe, the *abſolute gravity of the Pendulum, is its motive force.*

Alteration in the action of gravity will not alter the length of Vibration.

377. Nor would any alteration in the action of gravity, alter the length of the Vibrations; for, *the oppoſition to its aſcent*, increaſes and diminiſhes *as its power of deſcent*.

Times inverſely as the motive force.

And, the velocity of *ſuch Pendulum* will be as its motive force; and *its times*, inverſely as the velocity; i. e. *inverſely as its motive force*.

Comparative weight, the motive force.

378. But when a Pendulum vibrates in any heavy medium; its *comparative weight*, is the motive force; i. e. the weight of its bulk of the medium, being deducted from its abſolute weight, *the remainder only*, is its motive force *. *Therefore*,

In a non-reſiſting medium, cycloidal and circular Vibrations are on a level.

379. Any alteration in the denſity of the medium, will *alter* the *motive force* (378); and if ſuch *medium* be conſidered as *non-reſiſting*, *it* will not alter the *length of Vibration* (377); conſequently every alteration in its denſity, would by altering the motive force, cauſe equal alteration in the velocities and times, of ſuch Vibrations as were performed, in cycloidal or circular Arcs. *But*,

Not ſo in air.

380. *Air*, being a reſiſting medium; *its reſiſtance* will increaſe. &c. *as its denſity*, as will the effect of ſuch reſiſtance, in deſtroying the

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* See 6th Corol. Prop. 24. of Sir ISAAC NEWTON's Princip. Math. Vol. 2.

motion of the Pendulum; *and contracting its Arcs of Vibration*: therefore, *thoſe alterations that happen in the reſiſtance of the air* (conſidered ſeparately) *do not* affect the *times* *.

CYCLOIDAL AND CIRCULAR VIBRATIONS COMPARED.

The alteration in the length of Vibration, as that in the denſity of the air.

381. But, *the ſhorter Vibrations in circular Arcs* are performed in *leſs time* than the longer (19): therefore, any *increaſe of reſiſtance* of the air, *will*, by contracting ſuch Arcs, *alſo ſhorten the times* of Vibration: and *this effect* will always be, *as ſuch denſity of the air* (300) †.

Circular Arcs correct the effects of ſuch changes as happen in the denſity of the air.

382. Now, ſince any increaſe of denſity in the air, will, *independent of its reſiſtance*, prolong the times of cycloidal, as well as circular Vibrations, *in proportion to ſuch increaſe of denſity* (378); and as the *reſiſtance* of the air *is always as its denſity*, and contracts the Arcs of Vibration *in the ſame proportion*; it follows, that *in circular Arcs* the *reſiſtance* of the air, contracts the *times of Vibration* (19), as much, *as the diminution in the motive force* of the Pendulum, from ſuch change of denſity, prolongs *them* (378): And the contrary.

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* See notes (238, 19).

† The reſiſtance of the air does ſomewhat more prolong the time of deſcent, than it contracts the time of aſcent of a Pendulum; and this difference will increaſe, or diminiſh, with the total reſiſtance of the air in each Vibration: but the total reſiſtance to Clock Pendulums, is as the maintaining power (300); therefore, the *former* will be uniform, when the *latter* is ſo; and will in ſuch caſe, *equally* affect the time of each Vibration; which *uniform effect* is corrected in the length of the Pendulum.

CYCLOIDAL AND CIRCULAR VIBRATIONS COMPARED.

All the times of Vibration in Clocks rendered iſochronal.

383. Hence, a Clock-pendulum, having its motion continued by a maintaining power *perfectly uniform* (300), and at *liberty to enlarge its Arc of Vibration*, in proportion to the *diminution of denſity* in the air; and the contrary; will have all its Vibrations in *circular Arcs*, iſochronal (382); which *would not* happen in the cycloidal curve; in which, all the Vibrations *of whatever length, are iſochronal in a medium of uniform denſity only*, (379, 380). And thus it appears, that in CLOCK-PENDULUMS, *Vibrations performed in the Arc of a circle are much ſuperior*, to thoſe performed *in the cycloid*, when the maintaining power is uniform, and the denſity of the medium fluctuating*.

Circular Vibration better than cycloidal.

CONCLUSION.

Having thus endeavoured to inveſtigate ſeparately, the effect of each cauſe, that I imagine can influence the performance of a Clock; and compared ſuch effects, with their cauſes, in the preſent ſtate of Clock-work: I am therefrom induced to expect ſo much amendment in the performance, from the improvements already propoſed, as will render any further enquiry into the nature of pendulous Vibrations, of no material ſervice to *the immediate improvement* of Clock-work ; but if my leiſure, was equal to my inclination of eſtabliſhing a practical theory of Clock and Watch-work, and rendering it of general utility, I would not deſiſt, before I had made ſuch number of experiments, as would not only illuſtrate, but confirm, the truth of every improvement propoſed in this Eſſay : but prudence forbids an attempt, that requires ſo much time, expence, and application.

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* What is here objected to the cycloidal curve, is equally applicable to the friction on the pallets; the moſt perfect mode of a recoil, or any cauſe whatever, that has a tendency either to render the Vibrations of more equal length than is here propoſed; or to accelerate the Vibrations more, in proportion to their length. And if the nature of pallets is not ſo fully conſidered in this Eſſay as the reader could wiſh, it will be further explained in the next.

End of the Firſt Eſſay.

AN

ESSAY

TOWARDS THE

Improvement of WATCH-WORK.

IMPROVEMENT OF WATCH-WORK.

THE PLAN.

WATCH-WORK.

384. IT BEING UNIVERSALLY ALLOWED, *that Watches are as well executed as Clocks, but meaſure time worſe*; it naturally follows, that the defect ariſes, more from the imperfections of principle, than execution.

Errors ariſe from principle, more than execution.

385. I SHALL THEREFORE ENQUIRE,

Wherein do Watches differ from Clocks?

What defect will ariſe from each difference?

How? and in what degree? may thoſe defects be remedied?

Enquiries.

386. The articles wherein Watches differ from Clocks are,

Watches differ from Clocks.

FIRST, That in Clocks; the motion is generally maintained by weight; *but in Watches by ſprings.*—

SECONDLY, That in Clocks, the motion is regulated by a Pendulum; *but in Watches, by a Ballance and ſpiral Spring.*—

THIRDLY, Clocks are not capable of beginning their own Vibrations; *but Watches are.*

FOURTHLY, Clocks are larger *than Watches.* And,

FIFTHLY, Clocks are fixed in their place; *but Watches are portable.*

387. The above five articles, being all that occur to me, wherein Watches differ from Clocks; I ſhall enquire into the effect of each article ſeparately, and how it may be moſt effectually removed.

Clocks go by weight, &c.

Firſt inconveniency of Springs.

388. The firſt inconveniency of Springs, is that their action is not uniform, but diminiſhes as they unbend: but this is totally remedied by the application of a well adjuſted FUSEE.

Second Ditto.

389. Heat and cold, contract and dilate all metals; *and conſequently* alter the elaſtic force of Springs in ſuch manner, that their exertion is not the ſame at all times; but in a ſtate of fluctuation, depending on the temperature of the air, or the degree of heat or cold to which they may occaſionally be expoſed.

How remedied.

390. But this *evil*, however bad, is not incurable; for the ſame cauſe always producing the

ſame effect, *it* may with certainty be remedied by *an oppoſition of expanſion*; of which more when I treat of Thermometers.

Application of oil to the main Springs hurtful.

391. I have ſhewn (155), that the influence of heat and cold on the oil applied to the pallets, was of the moſt pernicious nature, as no remedy could be applied by oppoſition; the ſame is applicable to the oil applied to the main Spring; for the coils of the ſpring lying in many places in contact with each other, any change in the tenacity of the oil, may conſiderably alter the exertion of the Spring on the Fuſee; and conſequently the action of the wheels on the pallets.

Rendered unneceſſary.

392. But the uſe of oil on *main Springs* may be diſcontinued, by tapering *them* more towards the inner end; by which means the exterior coils being thickeſt, will ſooneſt unbend; and the exertion of the Spring will become progreſſive from its outer, to inner end, and one coil only act at a time; which will prevent all rubbing, and render the application of oil entirely unneceſſary: hence *its* action may (390) be rendered ſo uniform, that the greateſt effect of any remaining irregularities, cannot be perceived in the performance of a Watch.

Objection to tapering Springs.

393. It may poſſibly be objected, that the thickneſs of ſuch Springs may render their temper leſs perfect at the external, than the internal end; but it ſhould alſo be remembered, that the exterior parts of all Springs are bent round

Anſwered.

larger cylinders, than the interior, and therefore, require leſs perfect elaſticity; and if due care be taken that Springs be made as broad as the ſpace admits, and no part of their power miſapplied; I am apt to think that no ſenſible inconveniency or diſadvantage will attend the neceſſary thickneſs: but even admitting, that thicker Springs are more liable to break, than thinner ones; that which gives the moſt perfect performance while it laſts, is in *many caſes* to be preferred.

Conſideration of the method of diſengaging the wheels, reſumed.

394. When I examined the properties of Mr. Hugens's method of removing the effects of any irregularities of action in the main Spring (216, to 223), I propoſed reſuming that ſubject, in order to enquire, whether that ingenious contrivance would have *an equal effect in* PORTABLE MACHINES, as it was there allowed to have *in Spring Clocks that remain in their place* (221). The reader will pleaſe to remember, That

395. The chief advantage acquired in *the former caſe*, was owing to the ſwing wheel being moved by a ſmall *weight* (216); *which would have a direct contrary effect in a portable machine*, of whatever conſtruction: for the action of the weight on the ſwing wheel, would no longer remain uniform, but depend in a great meaſure on the direction and velocity, with which the machine was moved.

Illuſtration.

396. Example. If a heavy body falls freely, it will deſcend nearly ſixteen feet in a ſecond of time:

WATCHES BY SPRINGS.

time: but if two bodies fall together, and with equal velocities, they will be relatively at reſt; nor can the one, have the leaſt tendency to draw or propel the other: *and thus*, is the action of the ſmall weight on the ſwing wheel diminiſhed, in proportion to the velocity with which the whole machine deſcends; *and the contrary*; by which means, Mr. HUGENS's method of winding up his Marine-clocks every half minute, introduced greater irregularities in their maintaining power (while at ſea), than could ariſe from all the other imperfections of Spring Clocks taken together.

Springs ſubſtituted for weights.

397. Let us then ſuppoſe, a Spring or Springs, ſubſtituted for the weight; *it is obvious*, that every inconveniency ariſing from the motion of the *whole machine*, will be removed; but thoſe Springs, being as ſubject to the influences of heat and cold, as the main Spring, will be no improvement in this reſpect; for if any degree of heat or cold ſhould alter the exertion of thoſe ſmall Springs on the Ballance wheel, ſuppoſe $\frac{1}{1000}$ part of their whole force, it will affect the times of Vibration, *as much*, as if the main Spring had acted on the Ballance wheel, (without the interpoſition of ſuch ſmaller ſprings) and undergone an alteration of a $\frac{1}{1000}$ part of its *whole force:* for *in either caſe*, there is an alteration of $\frac{1}{1000}$ part *of the whole maintaining power*; and it was ſhewn formerly (80), that *the altera-*

No advantage.

tion in the meaſure of time depends, *(c. p.)* on the *alteration in the maintaining power:* therefore the performance of the Watch, will be no ways improved by the above means. *And,*

These ſmall Springs more influenced than the main Spring.

398. If this method of frequent winding up, does in portable machines, remove the influence of heat and cold on the main Spring: it introduces another effect, that is, *in every caſe* equal to it (397), and *ſuperior in many*; for, thoſe Springs that propel the Ballance wheel, being ſo much more ſlender and expoſed than the main Spring, are influenced by many ſuch changes of heat and cold, as have not ſufficient duration to affect the main Spring; and therefore, if we only regard the influence of heat and cold on the Springs, this method is hurtful.

No more than a 200th of the influence of the oil can be thus removed.

399. I have already ſhewn (392), how to evade the uſe of oil on the main Spring; and if the influence on all the pivots, thoſe of the Ballance and its wheel excepted, be removed by the diſengaging all the wheels but one; it has been already ſhewn, that *ſuch part of the influence* of the oil, is to its whole influence, *even in Clocks*; only as one to 199, (221): but it will ſtill bear a much leſs proportion to the whole, in Watches, where the influence on the Ballance pivots, and pallets, become much more conſiderable on account of the greater angles and number of Vibration, as well as the greater number of wheels.

400. But

Much more advantage gained by increaſing the maintaining power.

400. But admitting, that a 200th part of the influence of the oil, ſhould be removed by this means, a much greater advantage might be gained, by applying *ſuch part* of the action of the main Spring *as is in the above caſe loſt*; for by ſuch means, the influence of the oil would be diminiſhed in the inverſe duplicate proportion of the maintaining power (162): for, if a fifth part of the action of the Spring be thus loſt, the effect of the influence of the oil (on the meaſure of time), with the remaining four fifths, will be to its effect, with the whole action of the Spring, as 25 to 16 *; from which it evidently appears, that ſo far as relates to the influence of the oil, the advantage gained, by applying *the whole exertion* of the main Spring *to the pallets*, is, to the advantage gained, by diſengaging the wheels, nearly as 200 to 3.

RECAPITULATION.

401. It has been already ſhewn (398), that, ſo far as it regards the influence of heat and cold on Springs, this contrivance is hurtful; that, ſo far as relates to the influence of the oil, it has no better effect (400); and that, unleſs the periodical fluctuations, in the action of the wheels, have a ſenſible effect on the meaſure of time du-

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* For it appears that by increaſing the motive force of the wheels, as 5 to 4, the influence of the oil is diminiſhed as 16 to 25, that is, ſomewhat more than a third: but by diſengaging the wheels (however frequent) only a 200th part of the influence can be removed.

ring the action of one tooth, it never increaſes (54): and even admitting, that ſuch periodical fluctuations in the maintaining power, were hurtful; thoſe that happen, by unlocking the winding up part, in the above caſe, are not leſs ſo, than thoſe of the wheels and pinions.

The diſengaging the wheels, &c. can never be an advantage in any portable machine.

402. There does not then appear, the ſmalleſt ſhadow of improvement, *by thus diſengaging any number of the wheels, in portable machines of any kind*: on the contrary; by rendering thoſe periods of winding, more frequent, than will require the Springs that propel the Ballance wheel, *each as thick as the Ballance Spring*, the performance muſt be hurt*; and in 30 hour Watches whoſe Ballance Springs are of a proper ſtrength, the above rule, will not even admit of detaching one ſingle wheel, much leſs, of winding up every half minute; *therefore*, we may to good purpoſe *in all portable machines* ſave that labour, which this method of diſengaging the wheels would occaſion.

Maintaining power in Watches can never be rendered as uniform as in Clocks.

403. The method which I have given (300) for rendering the maintaining power in Clocks perfectly uniform; would *in portable machines* be liable to the ſame inconveniencies: *hence it would appear*, that in this reſpect, Watch-work muſt ever be inferior to Clocks: though, by a

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* This article will be explained, when Thermometers are treated of.

due attention to what has been ſaid in the former Eſſay relative to the maintaining power, and a *judicious* application of a Thermometer, the action on the pallets, in Watch-work, may be made to diſturb the times of Vibration, as little as it generally does in Clocks. *But*,

Experiment, and Concluſion.

404. He who prefers experiment to demonſtration may receive no ſmall ſatisfaction, relative to the errors that ariſe from all the imperfections of MAIN SPRINGS, even in their preſent ſtate, by comparing together the performance of two Clocks; *the one* with a weight, *the other*, with a Spring: and I will venture to aſſert from trials I have made; *that*, if the maintaining power, angle of Vibration, and weight of the Pendulum &c. be made equal in two ſuch Clocks; their performance will prove; *that a very ſmall part only, of the errors of Watch-work, is owing to the imperfections of the main Spring; even where no Thermometer is uſed to counteract it*[*].

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[*] Does not the ſame heat that lengthens the main Spring and chain, render the oil on the pivots more fluid, and increaſe the diameter of the Fuſee? by which means, it ſeems to me more than probable, that the exertion on the pallets is rendered more uniform, than if the action of the main Spring was ſubject to no alteration from heat or cold: for thoſe contrary effects tend to correct each other.

CLOCKS are regulated by a Pendulum;

WATCHES *by a Ballance and Spring.*

Plan of enquiry.

405. In order to inveſtigate this matter properly, it is neceſſary carefully to compare the Ballance and its Spring, with a Pendulum; and enquire, how far they ſhare the ſame properties: in order to which, I ſhall here recapitulate *the general properties of the detached Pendulum*, as ſtated in the foregoing Eſſay; that it may the more clearly appear, in what reſpects *thoſe of the Ballance*, do either agree with, or differ from *them.*

Firſt property of the Pendulum.

FIRST *Property of a Pendulum.*—

406. That, if once put in motion, it would ever continue to vibrate, if no external cauſe tended to deſtroy its motion.

Equalled in the Ballance.

The caſe is ſimilar in the Ballance; for the Spring in unbending, would communicate as much motion to the Ballance, as would enable it, (by means *of its vis viva) to bend the Spring as much in a contrary direction. Hence, it would vibrate without diminution, &c.*

Second Property of the Pendulum.

SECOND *Property of the Pendulum.*—

407. All its *equal* Vibrations would be performed in equal times.

The

CLOCKS REGULATED BY A PENDULUM, &c.

The ſame would happen with the Ballance and Spring: becauſe the motive force and ſpace deſcribed, remained unalterably the ſame (406).

THIRD *Property of the Pendulum.*—

Third property of the Pendulum.

408. Its momentum (in circular Vibrations) is as the verſed ſine of its angle of Vibration, into its quantity of matter: but it increaſes ſomewhat quicker, towards the extremities of cycloidal Vibrations; in which, the exertion of gravity on the Pendulum, is conſtantly as its diſtance from the point of reſt *.

More perfect in the Ballance.

In the Vibrations of the Ballance, the exertion of the Spring, is alſo conſtantly, as the diſtance of the Ballance from its point of reſt †; *and therefore its Vibrations, naturally have the properties of the cycloidal Pendulum, oſcillating in a medium of unalterable denſity* ‡; *and their momenta and velocities, at different diſtances from the point of reſt, &c. are to be eſtimated in the ſame manner.*

FOURTH *property of the Pendulum.*—

Fourth property of the Pendulum.

409. Thoſe of equal length, though unequal weight, will *(c. p.)* perform their Vibrations in equal times.

Equalled in the Ballance.

Likewiſe all Ballances wherein the vis inſita *and ſtrength of the Spring have the ſame proportion*;

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[*] See Sir ISAAC NEWTON's Prin. Prop. 53.

[†] See Dr. HOOK's Theory of Springs.

[‡] For ſuch changes as happen in the denſity of the air, do not alter the motive force of the Ballance, as they do that of the Pendulum (379).

will (c. p.) *perform their Vibrations in equal times.*

FIFTH *property of the Pendulum.* —

Fifth property of the Pendulum.

410. They alter their times of Vibration in different latitudes: (becauſe gravity is altered without the *vis inſita*)†.

Equalled in the Ballance and Spring.

A Ballance will alſo alter its times of Vibration, if the ſtrength of its Spring be altered; without altering its weight or ſize *.

A perfect equiliber of action and re-action

411. In the vibrating Pendulum; *gravity* is made by means of the *vis inſita*, to counteract *itſelf*: the *Ballance Spring* is alſo made to counteract *itſelf* in each Vibration, by means of the *vis inſita* of the Ballance; and *thus*, by having *the effect changed into the cauſe*, in each Vibration; we have, in the vibrating Pendulum, and in the Ballance and Spring, the moſt perfect equilibrium of action and re-action, that nature can produce ‡: *what can be more equal than any power to itſelf?* 412. Thus

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† In the Pendulum, gravity is the motive force; and in Ballance, the Spring: the *vis inſita* is the reſiſtance in each: and the contrary: therefore, when the motive force is in each, as the reſiſtance, the velocities and times muſt be equal. Hence it alſo happens that *(c. p.)* the Ballance meaſures the ſame time in all latitudes.

* Here, by altering the weight, is ſtrictly meant, altering the *vis inertiæ*; for the Vibrations of a Ballance, whoſe center of gravity coincides with its center of motion, have not the leaſt dependence on gravitation, otherwiſe it would alter its times in different latitudes, as well as the Pendulum.

‡ For this reaſon the vibrating Pendulum and the Ballance and Spring will always meaſure time better than ſuch as perform whole

WATCHES BY A BALLANCE AND SPRING.

The Ballance has all the properties of the Pendulum.

412. Thus we find; *that the Ballance and Spring*, are in full poſſeſſion of all thoſe properties of the Pendulum, on which the iſochroniſm of the Vibrations depend: the *vis inſita*, having the ſame effect *in each*; and *the Spring* producing that effect in the *Ballance*, that *gravity* does in the *Pendulum*. Therefore,

All that has been ſaid relative to the Pendulum, is equally applicable to the Ballance.

413. All that has been ſaid in the former Eſſay, relative to, *the length of Vibrations* (41, 47); *weight of the Pendulum* (79, 80); *quantity of maintaining power* (161, 162); *influences of the oil* (163, 164); *and conſtruction of pallets*, (189, 239, 263); is as applicable to *Watches*, as Clocks*, and need not here be repeated: but as the ſeveral articles wherein Watches differ from Clocks (386) require ſome conſiderations in the improvement of the *former*,

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whole revolutions: and where the centrifugal force is made to correct the velocity: for in this caſe, any alteration in the motive force will require a new adjuſtment of theſe two powers, which cannot take place till the change of velocity make ſuch an alteration in the centrifugal force as can overcome ſome ſmall degree of friction: therefore the motive force may remain for a conſiderable time, either too great or ſmall, for the reſiſtance, to render the revolutions iſochronal; and here the moſt trifling error may, by conſtant accumulation, become great (248): whereas in the common Pendulum, there is a new adjuſtment of the motive force and reſiſtance, at the point of reſt of each Vibration; where the effect is always changed into the cauſe.

* Obſerving always, that what is ſaid in the *One* of the mode or quantity of the exertion of gravity on the Pendulum, is to be underſtood in the *Other*, of the exertion of the Ballance Spring.

that

that were totally unneceſſary to the latter; I ſhall endeavour to point out, in what caſes, thoſe *additional improvements* co-operate with, or counteract, thoſe already propoſed.

Maintaining power cannot be rendered ſo perfect in Watches as in Clocks.

414. It has been already obſerved (403), that the maintaining power can never be rendered ſo uniform in Watches as it may in Clocks: but admitting the natural iſochroniſm of the Ballance (408), pallets may be ſo conſtructed, as to correct the *effect* of any changes of the maintaining power; by prolonging one half of the *time of Vibration*, as much as the *other* is contracted: which will have the ſame effect on the meaſure of time; *as rendering the maintaining power perfectly uniform.*

But the ſame effect may be otherwiſe produced.

Enquiry concerning the Ballance.

415. But let us now enquire, whether there are any probable reaſons, why the Ballance may not have the ſame advantages, in practice as in theory.

Exertion of its Spring conſidered as an innate force, &c.

416. *In the theory* of the Ballance (408), the action of the Spring was conſidered, as an innate property of the Ballance; whoſe exertion was in every part of the Vibration, as the diſtance of the Ballance from its natural point of reſt: but no regard was paid to the effects that might ariſe from the *vis inſita, or ſhape* of a Spring, acting in a ſpiral direction.

The effect of its *vis inſita.*

417. If all the matter of the Ballance Spring was collected into a circle, *concentric with the Ballance*, its *vis inſita* would have a ſimilar effect

feȼt to *that* of the Ballance; and would tend to promote the aȼtion, in the one half of the Vibration, as much as it oppoſed it, in the other; *and conſequently*, no part of the exertion of the Spring would be loſt, or deſtroyed by *its* means. But from the ſpiral form of the Ballance Spring, the *vis inſita* of all its parts, have contrary tendencies, and ſo deſtroy each other's effeȼts; ſo that it cannot promote the bending as much, as it retards the unbending: and thus is a part of the exertion of the Spring loſt in each Vibration, which muſt prolong the times. *But*

The exertion loſt as the length of Vibration. Hence the longer ones ſloweſt.

418. The part loſt of the exertion of the Spring is, *(c. p.)* as the mean motion of all the particles of the Spring taken together: hence it muſt increaſe with the angle of Vibration; and ſuch prolongation of times as it occaſions, muſt be greater, in the longer Vibrations than the ſhorter; and this I imagine is the caſe, in detached Ballances *with Springs of equal thickneſs. But*

The Vibrations rendered more iſochronal.

419. If the Spring be rendered thinner towards its inner end, the mean motion of its parts, will bear a leſs proportion to the angle of Vibration; and conſequently, the longer and ſhorter Vibrations will thereby be rendered more iſochronal; *and the ſame is true of all the other means*, by which, the mean motion of the Ballance Spring may be diminiſhed (418). *But*

420. As the Spring muſt have ſome degree of motion in any Vibration whatever the above conſideration *alone*, can never render the Vibrations truly iſochronal (418).

Mode of action conſidered.

421. But the longer Vibrations are rendered quicker in proportion to the ſhorter, with tapering Springs, on account of their mode of action, as well as the diminution of the *vis inertiæ*. *Thus*

The exertion of tapering ſpiral Springs progreſſive, &c.

422. If any power be applied to a Ballance, which tends to bend its Spring, the thinneſt part thereof will be ſooneſt bent; therefore a tapering Spring will begin to bend at its inner end, and as the reſiſtance of its thinner parts increaſe (408), the thicker parts are bent: by which means, the exertion of a ſpiral tapering Spring in bending, is at leaſt in ſome degree, *progreſſive from its thinneſt to its thickeſt end*; and in unbending, *the contrary*.

Different from ſtraight tapering Springs, &c.

423. It is evident, *that the mode of exertion of a tapering ſpiral Spring*, is different from *that* of a ſtraight Spring of *equal length, and taper*, where the power is applied at right angles to the Spring *.

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* The exertion of any power applied at the inner end of a tapering Spring, on any part of ſuch Spring, may be repreſented by two lines meeting at ſuch part of the Spring; the one at right angles, the other attangent to it: from which it is evident, that ſuch part as is repreſented by the line attangent, can have no

424. But the exertion of a Spring is, *(c. p.)* as its thickneſs; therefore (422), the exertion of a ſpiral tapering Spring, will increaſe more in proportion to the ſpaces to which it is bent, than that of a Spring of equal thickneſs.

Increaſes moſt towards the extremities in ſpiral Springs.

425. Hence, the longer Vibrations of a Ballance will be *quicker in proportion to the ſhorter ones*, with tapering Springs, than thoſe of equal thickneſs: *Therefore*,

The longer Vibrations quicker, with tapering Springs, &c.

426. There muſt be a certain degree of tapering of the Ballance Spring, that will *render* the Vibrations as iſochronal, as if the Spring was of *equal thickneſs*, and *deprived of its vis inertiæ* (417). And this I am alſo induced to believe by obſervation, as well as theory: *and moreover*, that, by tapering the Ballance Spring beyond the due pitch, the longer Vibrations of the detached Ballance, may be rendered quicker than ſhorter ones.

A certain degree of tapering will give the cycloidal properties, &c.

Or even render the longer ones quickeſt.

427. And though it may be impoſſible to determine by calculation, the exact ſhape that will give the above property; it may not be ſo difficult, to manufacture many, that will have the ſame property,

Many ſuch Springs may be manufactured, &c.

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no effect on the bending that part of the Spring, but acts like a cord in bending ſome other part of it, at the diſtance of a quarter of a turn from that point: and thus may a weaker part of a ſpiral Spring be made to bend a thicker, without being ſo much bent itſelf as if the Spring was ſtraight: and this accelerating effect of a tapering Spring will increaſe with the ſize of the collet to which it is attached.

property, when ſuch ſhape has been once found: and it may be aſcertained by trial, whether ſuch property is ſufficiently perfect before they be applied to a Watch.

All the properties of cycloidal Vibrations may be given the Ballance, even in practice.

428. And thus it would appear, that even in practice, all the properties of the cycloidal Vibrations of the Pendulum in a medium of *uniform denſity* may be given the Ballance and ſpiral Spring. *Therefore*,

Concluſion.

429. The great diſparity in the performance of CLOCKS and WATCHES, cannot be owing to the *former* being regulated by a Pendulum, and the *latter*, by a Ballance and ſpiral Spring: *we therefore come to conſider, the third article wherein Watches differ from Clocks.*

CLOCKS *are not capable of beginning their own Vibration : but* WATCHES *are.*

In all Clocks the action of gravity has more influence on the Pendulum.

430. If the action of the ſwing wheel was greater than that of gravity on a Clock Pendulum; ſuch Clock would begin its own Vibrations: but as no Clocks do, we may juſtly infer, that in all of them, the action of gravity has more influence on the Pendulum, than the action of the wheels has.

The contrary in Watches, &c.

431. *All Watches* begin their own Vibrations, becauſe the action of the wheels is equal to that

of the ſpiral Spring on the Ballance when the wheel eſcapes the pallets (486). And therefore Watches are, in this reſpect, *only on a par* with Clocks having ſuch light Pendulums that they would begin their own Vibrations (413).

Experiment propoſed, &c.

432. *Let ſuch a Clock be made* with an equal maintaining power as in Watches, and *its* performance will prove, that no ſmall part of the imperfections of Watch-work, is owing to *too ſmall maintaining powers* (164); and the ſtill ſmaller proportion, that the momentum of the Ballance bears to *them* (80, 81, 413, 487).

Illuſtration.

433. It is univerſally allowed that the lighteſt Pendulum has all the natural properties of the heavieſt: but will any aſſert, that one of an ounce weight, will *(c. p.)* have the ſame effect in correcting any irregularities of the maintaining power, as one of many pounds: ***and is not the caſe exactly ſimilar with a Ballance and Spring?*** (413)*.

The advantage increaſes with the ſtrength of the Ballance Spring, &c.

434. I ſhall hereafter have occaſion to enquire into the ſeveral ways of augmenting the momentum of the Ballance, when it will appear, that in every caſe, the advantage increaſes with

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* I ſhall, in an after part, conſider the improvements that muſt yet be made, before the momentum of the Ballance can be much augmented in Pocket-watches, with one Ballance, further than by augmenting the maintaining power and angle of Vibration, and diminiſhing the angle of ſcapement.

the

CLOCKS CANNOT BEGIN THEIR VIBRATIONS, &c.

the ſtrength of the Ballance Spring: *though not equally in all caſes* *.

435. Having here pointed out, *one of the greateſt cauſes of error in the performance of Watches*, I now come to the fourth article; wherein *they* differ from Clocks.

CLOCKS *are larger than* WATCHES.

Wherein Clocks have the advantage, &c.

436. Here alſo, Clocks have the advantage of portable machines, wherein the ſize is limited: as they admit of *ſtronger maintaining powers, and greater momentum in the Pendulum.*

Larger Watches have a like advantage, &c.

437. For the ſame reaſon; *a* LARGER WATCH will perform better than a ſmaller: for, though the maintaining power may bear the ſame proportion to the *weight* of the Ballance in each; *the influences of the oil* will always bear the greateſt proportion to the leaſt maintaining power (161 to 164): therefore, the greateſt care is to be taken, to acquire in all Watches as great a maintaining power as circumſtances can admit: which of courſe increaſes the momentum of the Ballance, by which means a double advantage is gained (162, 490).

The Wheels ſhould be made light, &c.

438. As to the wheels; *they, only ſerving to tranſmit the action of the main Spring to the Ballance,*

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* Since all that has been ſaid relative to the exertion of the Ballance Spring is equally applicable to the exertion of gravity on the Pendulum (413); it follows, that the more the Arc of Vibration of a Pendulum approaches a ſtraight line, i. e. the ſhorter the Arc (See Plate 12. Fig. 2.) the worſe the performance of the Clock.

lance, and *to number its Vibrations*; ſhould be made no larger or heavier, than is abſolutely neceſſary, to perform their reſpective offices with ſafety; and the judicious mechanic may diſplay his ſkill, by duly proportioning the ſtrength of each wheel, and the ſeveral parts thereof, to the preſſure it has to ſuſtain.

CLOCKS ARE LARGER THAN WATCHES.

439. Some are inclinable to think, that great advantage is gained by having large wheels, as they may be executed with greater accuracy: but when the theory of wheel-work, and the proper methods of execution, are thoroughly underſtood, this imaginary advantage will vaniſh.

The advantage of large Wheels imaginary.

440. *But*, the diſadvantages of *large heavy wheels*, are of more weight, for heavier wheels require thicker pivots, which increaſes the influence of the oil in proportion to the ſize of the pivots; and the friction, in the proportion to the ſize of the pivots, and weight of the wheel, jointly; which diminiſhes the maintaining power: as does alſo, the *vis inertiæ* of the wheels; which increaſes as their weight, and is to be overcome at each Vibration of the Ballance.

Diſadvantages of heavy Wheels, &c.

441. *On the whole it appears*; that, the more Watches approximate Clocks in point of maintaining power, and momentum of the Ballance, the more is their performance improved (413): and that, though an increaſe of external ſize is neceſſary to acquire thoſe advantages; it is not always a certain proof of their being acquired.—

Concluſion, &c.

I now come to the fifth article, wherein Watches differ from Clocks.——

CLOCKS *are fixed in their place, but* WATCHES *are portable.*

442. As the above difference gives riſe to an error in Watches, to which Clocks are only in a very ſmall degree liable; *I ſhall endeavour to ſhew*, by what means any EXTERNAL MOTION of a Watch does influence its times of Vibration: what kind of motion has the greateſt influence: and by what means thoſe influences may be evaded or corrected. Plan.

Machine deſcribed. 443. Plate 12. Fig. 1. repreſents a machine intended to illuſtrate this theory experimentally.

A B C D, is a ſquare board, or frame, on which moves round a hollow ſocket, (through which theverge or axis of the Ballance paſſes).

E F G, a round board, or plate of metal, to which is attached the one end of a ſpiral Spring: the other end of which is fixed to a ſmall collet near the center of the Ballance N O, in every reſpect in the ſame manner as the Ballance Spring is applied in Watches.

L M, a ſcale fixed to the board E F G, and ſerves to ſhew the relative motion of the Ballance therewith; by means of a mark made on the Ballance (when at reſt) oppoſite the middle of the ſcale: hence, as this mark recedes from, or approaches the middle of the ſcale; the Ballance is ſaid to recede from, or approach, its POINT OF REST.

INFLUENCE OF EXTERNAL MOTION.

I K, is a ſcale on the board A B C D, having holes in it correſponding with the diviſions of L M; by means of a ſmall pin occaſionally put in either of theſe holes, the board E F G, (when diſengaged from the catch H), may be made to move any number of ſpaces, and with different velocities, by the action of a weight or weights, ſuſpended to the end of a ſmall pliable cord, which is applied round the circumference of the board E F G, and paſſes over a pulley at B.

Uſe of the machine.

444. Now if the board E F G, repreſent the frame of a Watch, and N O, the Ballance: and the former be made to move any number of ſpaces on the ſcale I K; the influences of ſuch motion on the Ballance, with Springs of different ſtrength, Ballances of different weight, and motions of different angles and velocities, will be given on the ſcale L M; for it matters not, whether the ballance of a Watch deſcribes a certain number of degrees on the frame; or the frame moves the ſame, and the Ballance remain at reſt; for in either caſe, *their relative motion is the ſame*, and will allow one tooth of the wheel which acts on the Ballance, to paſs at *each relative Vibration*; and the time ſhewn by a Watch depends on the number of ſuch teeth, that eſcape the pallets, whether owing to the *abſolute*, or *relative* motion of the Ballance.

One tooth paſſes each relative Vibration.

Influence of external motion.

Introduction to the experiments.

445. I ſhall therefore here ſuggeſt, a few of the many experiments, that may be made with this machine, to illuſtrate the influences of external motion.

Experiment.

446. Let the ſpiral Spring be taken from the Ballance, and the Index F, be made to move any number of diviſions on the ſcale I K; the Ballance will retain its poſition by means of its *vis inertiæ*; and ſo be made to deſcribe as many ſpaces on the ſcale L M, as the Index F, does on the ſcale I K*.

Application.

Influence of external motion greateſt, when no Spring is applied to the Ballance.

447. This experiment ſhews, that any external motion of a Watch, will *(c. p.)* have the greateſt influence poſſible on its performance, when no Spring is applied to its Ballance (444); for in this experiment, the influence of external motion (ſhewn on the ſcale L M), is equal to the external motion, on the ſcale I K.

Experiment.

448. Let the point N, of the Ballance, be brought to the middle of the ſcale, and the whole

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* It is here to be underſtood, that the motion be not very ſlow; for in that caſe, the friction on the pivots might occaſion the Ballance to move with the ſcale, and preſerve its relative poſition.

machine be moved in a ſtraight line, with any velocity, or in any direction, the relative poſition of the Ballance and frame, will be no wiſe altered by ſuch motion.

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Application.

449. This experiment ſhews, that rectilineal motions do not influence the times of Vibration (442): but it is here underſtood, that *every point* of the machine, as well as its center of gravity, deſcribes a ſtraight line; for in ſuch caſe only, will the machine keep parallel to its firſt poſition, on which alone the property depends *.

Rectilineation does not influence the times, &c.

Experiment.

450. Let a long beam of wood be fixed at right angles to an axis, round which let it move on pivots: if the above machine be attached to the beam, at any diſtance from the axis, in ſuch manner, that the plane of the Ballance be parallel to the axis of the beam, the relative poſition of the Ballance with its frame, will not be altered by any motion of the beam round its axis, what-

PLATE XII. FIG. 3.

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* Though rectilineal motion does not of itſelf any how influence the times of Vibration: it may, by increaſing the friction on the Ballance pivots, alter the length of Vibration, and by that means introduce the effect of any imperfection of the Ballance Spring and pallets: but in Watches where theſe are perfect, ſuch friction will not alter the times.

ever

Influence of external motion.

ever be the angle or velocity of ſuch motion, or the diſtance of the machine from the axis.

Application.

What curvilineal motions do influence the times, &c.

451. This experiment ſhews, that no curvilineal motions, that do not in ſome degree, incline to the direction of the Vibrations of the Ballance, can influence its times of Vibration *.

Experiment.

452. Let the foregoing experiment be repeated, with the axis of the Ballance parallel to that of the beam; and the relative motion of the Ballance on its ſcale, will always be as the angle deſcribed by the beam, without regard to

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* Therefore a Watch carried on ſhipboard cannot have its times of Vibrations influenced by any motion, or motions, whoſe axils are parallel to the plane of the Ballance. Hence the beſt poſition for a Watch that is carried on ſhipboard, is to have the plane of its Ballance nearly parallel to the decks: (unleſs ſome internal defect, *ariſing from the execution*, ſhould render the performance more imperfect in this than in its other poſitions.) It is alſo to be obſerved, that the beſt place in a ſhip for laying a Watch in, is near its center of gravity; for here the agitation is the leaſt. It may poſſibly here be enquired, From what internal defects a Watch does meaſure time differently, in its different poſitions? But ſuch enquiry being entirely foreign to the general theory of Watch-work, (the defect ariſing ſolely from imperfections of execution) I ſhall only here obſerve, that if a Watch is adjuſted in ſix poſitions, at right angles to each other, it will meaſure equal time, in all the other poſitions into which it can poſſibly be put; they being all compounded of the former.

the place of the machine, whether at the center, extremity, or any intermediate part of the beam.

INFLUENCE OF EXTERNAL MOTION.

Application.

Effects of curvilineal motion.

453. This experiment ſhews, that the influence of any curvilineal motion, even in the direction of the Vibrations of a Ballance, does only take place *(c. p.)* in proportion to the angle, which it would make the Ballance deſcribe round its own axis (446); which is always equal to the angle moved by the beam *), without regard to the diſtance of the machine from the axis, or center of motion: and thus we ſee, why the Vibrations of a Ballance are much more diſturbed in the pocket, or in a carriage, than on ſhip-board.

Watches more influenced in the pocket than on ſhipboard.

Curvilineal motion otherwiſe conſidered.

454. *The reſult of the fourth experiment may alſo be expreſſed thus:* The influence of any external motion, on the times of Vibration of a Ballance, is, *(c. p.)* as the deviation which ſuch motion occaſions in the paralleliſm of the machine from its former poſition; which alſo (by 29 of 1ſt of Euclid), is always equal to the angle deſcribed by the beam. See Plate 12. Fig. 3.

Elaſtic force of the Spring diminiſhes the influence of external motion.

455. The following experiments all tend to prove, that the influence of external motion, is, in all caſes, diminiſhed, by the application of a

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* See Plate 12. Fig. 3.

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Spring to the Ballance; and that, in proportion to the ſtrength of the Spring; *the Ballance remaining the ſame.*

Experiment.

PLATE XII. FIG. 1.

456. Let a Spring be applied to the Ballance, as repreſented in the Fig. and the index F, be made to move any number of diviſions on its ſcale (as in former experiments); the motion of the point N, on the ſcale L M, will be diminiſhed by the exertion of the Spring; and with Springs of *double* and *triple*, &c. ſtrength, it will yet be diminiſhed *(c. p.)* to a *half* and a *third*, &c.

457. But a Spring of double or triple, &c. ſtrength, would make the ſame Ballance vibrate, double, triple, &c. the number of Vibrations in the ſame time; therefore, (456) the influences of external motion *on a ſingle Vibration of a Ballance*, will be diminiſhed with the time of its Vibration. *Hence, alſo*

Influence of external motion equal in all Watches having equal trains, &c.

458. In all Watches having *equal trains*, the influence of external motion is, *c. p.* the ſame, *without regard to the ſtrength of their relative Ballance Springs*: for in each, the weight of the Ballance, muſt have the ſame proportion to the ſtrength of the Spring (409), and an increaſe of the former *augments* the influence of external motion, in the ſame proportion, that an increaſe of

INFLUENCE OF EXTERNAL MOTION.

of the latter *diminiſhes it*: as may be proved experimentally, by applying rings of different weights to the Ballance, (by means of the ſmall holes at N and O,) ſo as to double or triple its weight with the ſame Spring.

PLATE XII. FIG. I.

Foregoing experiments made with Ballances at reſt, &c.

459. And though ſome of the foregoing experiments are made on Ballances that have neither the action of a Spring or wheels, to give them motion (446, 448, 450, 452), and all the others on Ballances at reſt (456, 458,) where the external influence *always generates motion* in the Ballance, which is not the caſe with a Ballance that performs its Vibrations during the experiment; for its motion will be *increaſed* or *diminiſhed*, as it happens in the *ſame*, or *a contrary* direction with the external motion. *But*,

Influences the ſame, whether the Ballance be in motion or at reſt, &c.

460. The relative influence on a ſingle Vibration, would be the ſame as above ſtated, whether the Ballance was at reſt, or vibrating, at the beginning of each experiment: or whether the external motion happens to oppoſe, or conſpire with, that of the Ballance: See Sir ISAAC NEWTON's II. law of motion*.

Introduction to the influences on many Vibrations.

461. Having thus laid a foundation, for diminiſhing (443, 449, 454), as well as eſtimating, *the influence of external motion*, on *a ſingle Vi-*

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* Hence thoſe Watches whoſe Ballances, when at reſt, are leaſt liable to be diſturbed, or begin their Vibrations by the influence of external motion, have their Vibrations alſo leaſt influenced.

bration : I now come to conſider *its* effect *on many*.

Illuſtration, by a Watch on ſhipboard.

462. If a Watch be ſo placed in a ſhip, that the axis of the Ballance lies parallel to the axis of the ſhip's greateſt motion ; and *the angular motion of the ſhip* be equal, *to the angle of Vibration of the Ballance*, and performed in the ſame time : if thoſe two equal angular motions happen to *oppoſe* each other, the former will deſtroy the latter (452, 453), and the Watch come to reſt. *But*,

In a double angle of Vibration, the influence only half.

463. If the angular motion of the Ballance had been *double* that of the ſhip ; the latter could only have deſtroyed one half of the former (453). *And therefore*,

464. The influence of external motion will be *(cæt. par.)* in the inverſe proportion of the angle of Vibration of the Ballance to the angular motion of the ſhip (462). *But the angle of Vibration increaſes, with the maintaining power* ; therefore, *the influence of external motion is diminiſhed by increaſing the maintaining power* (463).

And diminiſhed by increaſing the maintaining power.

If two Vibrations be performed, the one corrects the other.

465. If *one Vibration only*, be performed during one motion of the ſhip ; it will be accelerated or retarded (460) in the above mentioned proportion (464) : but *if two Vibrations* be performed, each will receive half the influence, that is, the *one will be accelerated* as much as *the other is retarded* (460) ; and conſequently, *both* be performed

formed in the ſame time, as if no external cauſe had influenced them : *Thus*,

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Thoſe of half duration have duplicate advantage.

466. Vibrations of half the duration have a *duplicate* advantage ; for the ſame cauſe, will only produce half the effect (452), and they alſo have a double chance of correcting each other (465) : add to this, that if the whole cauſe did take place, its effect would be diminiſhed by the ſuperior ſtrength of the Spring (456). Hence,

The total influence of external motion in the inverſe duplicate proportion of the train.

467. *The influence of external motion, on the performance of a Watch is diminiſhed, at leaſt in the inverſe duplicate proportion of its train :* (or number of beats in a given time). And therefore,

Application.

468. If two Watches be made in every reſpect alike ; *only* that the one ſhall vibrate *five*, the other *ſix times* in a ſecond, the relative influences of external motion on thoſe Watches will be, inverſely as the ſquares of their number of Vibrations : *that is*, on the former, to the latter, as 36 to 25 : Hence *,

Inference.

469. We may reaſonably entertain hope of diminiſhing the influence of external motion by ſuch means, (and without any additional parts) to ſuch a degree, as will ſcarce leave a chance of a Watch with one Ballance, ſtopping in the pocket.

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* It is here ſuppoſed that the angles of Vibration are equal in ſuch Watches.

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The only means of introducing ſtrong Ballance Springs, &c.

470. And this merits the more ſerious attention, that it ſeems the *only means of introducing ſtrong Ballance Springs and heavy Ballances*, into *Pocket-watches*; for until the chances of ſtoping (or ſetting) in the pocket, are much more diminiſhed than at preſent [*]; we muſt continue the practice of HALF-TIMING; that is, rendering the exertion of the wheels equal or nearly ſo to that of the ſpiral Spring, on the Ballance, *at beginning of its Vibrations:* the diſadvantages of which, and the advantages that may be gained by a contrary practice (468, 469), will appear more evident, by peruſing what is ſaid in the former Eſſay from (70 to 79); which is equally applicable here (413).

Half timing, what.

Objection.

471. I doubt not, that ſome will here remark, that every Vibration has its friction, &c. *and conſequently*, that by increaſing the number of Vibrations in a given time, the friction and influences of the oil are alſo increaſed, and the performance thereby much hurt, and the parts ſooner impaired. *But*,

To be anſwered hereafter.

472. Thus mentioning *the dreaded evil*, may here convince, that it has not eſcaped ne-

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[*] Thus it appears, why the Ballance Spring, in all Pocket-watches, is made nearly of the ſame ſtrength with the action of the wheels: for if a Watch having a ſtrong Spring, and heavy Ballance, happens to ſet in the pocket, by means of any ſudden jolt, it muſt continue at reſt, till again put in motion by its wearer, or ſome other motion equally violent.

tice: and before this Eſſay is concluded, I ſhall endeavour to ſhew, not only, that the train may be increaſed to the degree already propoſed (468), *but even doubled*, without increaſing the *total influence of the oil*, or friction, beyond what now takes place in the beſt horizontal Watches with common trains: not to mention the diminution that a due increaſe of maintaining power may occaſion in the effect of ſuch influence of the oil. (413. 161 to 164.)

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473. Having now pointed out the means that appear to me, the moſt ſimple and advantageous, for diminiſhing the influence of external motion in ALL PORTABLE MACHINES; and the *only means* by which it can be diminiſhed in Pocket Watches, *with one Ballance*; to ſuch a degree as to admit of a general reformation of principle (470), I ſhall now mention the means that have been heretofore uſed for this purpoſe; leſt I ſhould be accuſed of having here invidiouſly paſſed them in ſilence.

Introduction to the means that have already been uſed.

474. Dr. HOOK about the year 1658 applied to Watches, *two equal Ballances*, ſo connected that they ſhould vibrate equal angles, *but in contrary directions*; by which means the *one* muſt always be accelerated as much as the *other* is retarded, by the influence of any external motion; and thus, their *mean motion* could never be altered by any external influence.

Dr. Hook's method.

475. If

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Illuſtrated.

PLATE XIII. FIG. 1.

475. If the experiment (446) be made with the machine repreſented in Plate 13. Fig. 1. each Ballance will have the ſame relative motion with the frame; and thoſe parts of their circumference that are neareſt each other will have equal relative velocities *in contrary directions* (as repreſented by the darts) and the Ballances are ſuppoſed equal alſo: therefore, if their circumferences be any how connected, thoſe equal and contrary motions of the Ballances will correct each other *.

Its inconveniencies, &c.

476. The above very ingenious contrivance, proves its author to be intimately acquainted with the laws of motion, and quick in their application: but here the practice falls ſhort of the theory; for when the Ballances are connected by means of teeth, there ariſes a reſiſtance, which, however ſmall, when applied in this *moſt delicate part*, will tend to diminiſh the momentum of the Ballances; and if the leaſt *irregularity of action* ſhould

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* I have ſeen a Watch, made in the year 1715, with intention to diſcover the longitude, (as appears by an inſcription on it) in which, amongſt ſeveral laborious contrivances applied, were two Ballances; each of which had on its axis a pinion, and both of them were moved by the ſame wheel, on whoſe axis were the pallets (ſee Plate 13. Fig. 3.): by which means both Ballances were made to move in the *ſame direction*, and conſequently (475) rendered as liable to the influences of external motion, as one Ballance. This ſhews, how general rules, or even the beſt principles, may be miſapplied, when their elements are not properly underſtood.

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ſhould take place near the extremity, or *vertex* of the Vibration, it muſt be attended with the moſt pernicious effect. *But,*

How diminiſhed.

477. In order to diminiſh the above inconveniencies, the Ballances were connected by means of two ſmall wheels, fixed on the arbors of the Ballances, as repreſented by Fig. 2. Plate 13. * and though ſome ingenious means have been uſed, to evade the irregularities of action in ſuch wheels, I paſs them here, as alſo attended with their inconveniencies, and in every reſpect, *leſs fit for general uſe.*

PLATE XIII. FIG. 2.

Mr. Hugens's method.

478. Mr. HUGENS has, in his *Marine-clocks* already mentioned (216), uſed *a different* method of removing the influences of external motion; by preſerving the parallelism of poſition (454): but though this might, if perfectly attained, have the deſired effect on the Vibrations of a Ballance, where the centers of gravity and motion coincide; it would by no means have the ſame effect on the Vibrations of a Pendulum (where they do not); but the Pendulum can never be ren-

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* It is not improbable that this method and manner may, with ſome further improvements, be yet applied to good purpoſe in Pocket-watches; in which caſe the weight of the Ballances, and ſtrength of their Spring, (or Springs) may be increaſed at pleaſure. But it ſeems not clear, that diminiſhing the ſize of thoſe wheels that connect the Ballances, to any great degree, is advantageous, ſince by ſuch means each tooth muſt ſubtend the greater angle at the center of the Ballance; and conſequently be the more liable to the inconveniency mentioned in Par. 476.

dered ſit for any portable machine, even at ſea, for reaſons too many to be here mentioned, as no material advantage occurs to me that would follow.

Mr. Harriſon united them in the ſame machine.

479. Mr. JOHN HARRISON of *Red Lion Square*, has, in each of his three *large machines* for meaſuring time at ſea, united both thoſe methods of diminiſhing the influences of external motion; and diſplayed great mechanical abilities, in diminiſhing the friction, and making the centers of gravity and univerſal motion of the whole machine, more nearly to conicide than in Mr. HUGENS's Clocks: but I avoid any remarks on the properties, &c. as there is reaſon to expect a full account of all his ingenious performances will be ſoon made public.

Introduction to remarks.

480. Having thus mentioned the different methods that may be uſed, for diminiſhing the influences of external motion (468, 474, 478): *I ſhall conclude with a few remarks on their relative advantages.*

Mr. Hugens's only fit for large machines.

481. Mr. HUGENS's method, from its nature and ſize, can never be applied to Pocket-watches; and therefore its uſe is wholly confined to ſuch machines as are carried on ſhip-board: nor can its effect in thoſe be perfect, unleſs the center of gravity of the whole machine coincide with its center of univerſal motion, and the friction of its ſuſpenſion be totally annihilated: *in which caſe*, though the *whole machine* would have no ten-

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dency to vibrate, *it* would retain any poſition, which by accident it had got: and thus, a new inconvenience and error in the performance might ariſe, owing to the machine going in an unuſual poſition; (probably upſide down); nor can the friction of ſuſpenſion ever be removed to ſuch a degree as to prevent this inconvenience: *if it could*, THE LONGITUDE might be aſcertained without any meaſure of time. Let us then conſider the effect of rendering the center of gravity ſo much lower than the univerſal center of motion, as would regain the former poſition of the machine, if by any means loſt. It is obvious that by ſuch means, the influence of any *motion of the ſhip*, would be diminiſhed during *its time of continuation*; but the *effects* of ſuch motion would be continued while the machine retained thoſe Vibrations, of which the ſhip's motion was the firſt cauſe (453)*; from which it would ſeem, that a diminution of friction continues the effect for ſeveral Vibrations, if it diminiſhes it in one: hence, it is more calculated to diſtribute the influence of the ſhip's motion among many Vibrations, than to deſtroy it †.

Diminution of friction more calculated to diſtribute than to deſtroy the effect, &c.

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[*] And every Vibration of the machine will have the ſame effect, as if the ſhip had moved an equal angle (453).

[†] This method of preſerving the paralleliſm of the machine may in ſome caſes be uſed, to remove the riſque of ſome parts of the machine being diſplaced, bent, or broke. But this ſuppoſes very great imperfection in the conſtruction.

Dr. Hook's method incomparable in theory.

482. Dr. HOOK's method, with a double Ballance, would moſt certainly have all the deſired effect; if the inconveniencies already mentioned could be removed (476); in which caſe, it would in every reſpect be ſuperior to Mr. HUGENS's: for it would totally remove the influences of any external motion; by which means *every advantage of a heavy Ballance and ſtrong Spring* might be introduced, even into Pocket-watches.

Increaſing the train, preferable to any of the other methods, ſo far as the nature of materials will admit.

483. The method propoſed for diminiſhing the influence of external motion by increaſing the train (468), is entirely free from the inconveniencies of Dr. HOOK's (476); and if the influence of the oil, on the Ballance pivots, be increaſed in the *former*, as the number of Vibrations; it is doubled in the *latter*, by having twice the number of pivots: and when we conſider, that by ſhortening the time of Vibration, the influences of the external motion is alſo reduced (466); that if the time remained the ſame, the influences would be diminiſhed, *as the weight of the Ballance to the ſtrength of the Spring* (456); that when two Vibrations are performed during one motion of the ſhip; *the one corrects the other* (465): and hence, that it is, *the odd Vibrations only*, that are influenced; and that, in the inverſe duplicate ratio of its time, to that of the external motion (464, 465), that the more frequent (or quick) the Vibrations, *the more commeaſurable* do the times of two Vibrations become

INFLUENCE OF EXTERNAL MOTION.

to the time of one motion of the ſhip; and if we add to this, that by thus diminiſhing the influences of external motion, we alſo diminiſh the proportion that the maintaining power bears to the whole motive force of the Ballance; we ſhall ſee good reaſon for preferring this, to any other method, *ſo far as the nature of materials and oil will admit.*

Concluſion.

484. Having thus endeavoured to ſhew, how external motions influence the times of all portable machines; and what are the advantages, &c. of *each method* of diminiſhing ſuch influence*; *I next enquire* into the advantages that may be gained by the different ways of increaſing the momentum of a Ballance.

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* It has already been obſerved, that when any external motion *oppoſes* that of the Ballance, the utmoſt effect it can have is to ſtop the Watch. On the other hand, if it increaſes the motion of the Ballance, its utmoſt effect will be, to make the Ballance BANK; i. e. to make it ſtrike againſt the limits of its greateſt Vibrations: for by this means ſeveral ſubſequent Vibrations are ſo much accelerated as to become very ſenſible to the ear. But this evil may be very much diminiſhed, if not annihilated, by making the Ballance communicate its *exceſs of motion* to ſmaller ones, which have no concern with the meaſure of time, and againſt which the main Ballance is made to bank, as repreſented by the 4th Fig. of Plate 13th, where the ſmall ſpiral Spring ſerves only to keep thoſe Ballances to a certain poſition, in which the other may always find them.

Of the Momentum of the Ballance.

Introduction.

485. Since the exertion of a Spring is as the ſpace to which it is bent (408); *it follows*, that if no other force actuate the Ballance, its motive force will be, in all its Vibrations, as the length of the Vibration; and conſequently, *the ſpaces deſcribed*, and the *motive force*, will be expreſſed by the ſame numbers.

Motive force of the Ballance.

486. And if *in half-timed Watches* the ſhorteſt Vibration, *that can allow the wheel to eſcape the pallets*, be expreſſed by one: the maintaining power will alſo be expreſſed by one (470), and the motive force of the Ballance, be equally compoſed of the action of the wheels, and Ballance Spring. *But*,

It bears a greater proportion to the action of the Ballance wheel in long than in ſhort Vibrations.

487. If the Vibration be increaſed by the action of the wheels accumulated in the Ballance, as 2, 3, 4, 5, 6, &c. the exertion of the ſpiral Spring will increaſe in the ſame proportion (485); and the maintaining power (remaining the ſame) will only conſtitute $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, $\frac{1}{6}$, $\frac{1}{7}$; &c. of the motive force of the Ballance *. *Hence*,

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* And ſince the proportion of the whole motive force of the Ballance to the maintaining power, is thus increaſed as the *length of the Vibration*, it follows, that every endeavour ſhould be uſed to enlarge *it*; and that ſuch changes as may happen in the maintaining power, will cauſe leſs error with long than ſhort Vibrations (80).

488. Any

MOMENTUM OF THE BALLANCE.

488. Any change that happens in the maintaining power, will bear a leſs proportion to the whole motive force of the Ballance, in its longer Vibrations than its ſhorter ones, and conſequently (80), will leſs alter the times *.

Influence of external motion leaſt, in long Vibrations.

489. The influence of external motion is alſo diminiſhed, by increaſing the *angle of Vibration* (464); therefore (488), every endeavour ſhould be uſed to enlarge *it*, and to remove every cauſe that can have any tendency to diminiſh *it*: as friction, influence of the oil, and the reſiſtance of the air; of which hereafter.

Concluſion, relative to the advantage of long Vibrations.

490 And thus it appears (488, 489), how advantageous it is, *to increaſe the* MOMENTUM of the Ballance, *by increaſing its length of Vibration*; and the length of Vibration increaſes with the maintaining power: hence, &c.

Increaſed by augmenting the diameter of the Ballance, &c.

491. But the velocity, and conſequently the MOMENTUM of a Ballance, may be increaſed, *by enlarging its diameter*: and though this method *does not diminiſh the influence of external motion*, it does the riſque of breaking or bending the Ballance pivots, by a fall or any other violent motion; but if the friction on the pivots be diminiſhed

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* On this account, when the oil becomes glutinous on the Ballance pivots, the Vibrations become ſhorter, and ſenſibly quicker, even though the diminution of recoil has a contrary tendency.

MOMENTUM OF THE BALLANCE.

miniſhed by this means, *the reſiſtance of the air is augmented* *.

Increaſed by augmenting the weight of the Ballance, &c.

492. Since the MOMENTUM *is as the quantity of matter into the velocity*, it may be augmented by increaſing the *former*, as well as the *latter*: hence, a Ballance of twice the weight *will (c. p.) have double* MOMENTUM; and an equal effect in correcting the irregularities of the maintaining power, as one of twice the diameter, and half the weight.

Both ways compared, &c.

493. And if the friction on the pivots be increaſed as the weight †, the reſiſtance of the air will be diminiſhed in the *duplicate* proportion of the diameter ‡: hence the only article which renders this method of increaſing the momentum inferior to the former (491), is the greater riſque of the pivots, by falls, &c.

Increaſed by the number of beats, with the advantages therefrom.

494. *Laſtly*, if the MOMENTUM be augmented by increaſing the ſtrength of the Ballance Spring, *and conſequently the number of beats*; it

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* And unleſs all the Vibrations of the Ballance and Spring are truly iſochronal in their detached ſtate, and the maintaining power be ſo applied as not to diſturb thoſe natural properties, any change that happens in the denſity of the air, will, by altering the length of the Vibrations, introduce ſuch errors; and that more or leſs, *(c. p.)* in proportion to the total increaſe of reſiſtance.

† The friction on the Ballance pivots may be much diminiſhed, by applying two Springs to the Ballance, attached to its collet, diametrically oppoſite to each other, as in Plate 12. Fig. 4.

‡ See Note 491.

will have all the advantages of the former methods in correcting the effects of any irregularities of the maintaining power: and, if it increaſes the friction on the pivots, and the reſiſtance of the air; it diminiſhes the influence of external motion (469), to ſuch a degree, as to prevent the danger of a Watch ſetting in the pocket: and by that means paves the way for ſuch increaſe of momentum, by either or both the methods laſt mentioned (491, 492), as may give to the Ballance in Watches, the ſame advantages in regulating the motion of the Wheels, as Pendulums have in Clocks. MOMENTUM OF THE BALLANCE.

495. *And thus*, may the performance of Watches be made, in this reſpect, to approximate that of Clocks, as much as the nature of things can probably admit: and if due regard be paid to what has been formerly ſaid concerning the influence of external motion (451), any further attempts of diminiſhing its effect on machines carried on ſhip-board, will be rendered unneceſſary, even for the nicer purpoſes of navigation. Concluſion.

Of the THERMOMETER.

496. In order the better to inveſtigate the real effect of each particular cauſe, *the temperature of the air, has hitherto been conſidered as invariably the ſame*; but now, the effect of ſuch changes Introduction.

changes as happen therein, together with the moſt effectual means of removing them, claim our whole attention.

Influence on the main Spring.

497. Heat dilates, and cold contracts all metals; hence, the main Springs of Watches, &c. act more or leſs vigorouſly in proportion to the degree of heat or cold to which they are expoſed: and if no other cauſe of error took place in Watches, *with pallets of the common conſtruction*, they would go *faſter in cold* than in warm weather.

On the oil.

498. *Cold* renders oil thick, and *warmth* makes it more fluid: and if this cauſe alone, took place, it would (by an increaſe of the maintaining power), make Watches go *faſter in warm* weather than in cold. But,

Thoſe two influences oppoſe each other, &c.

499. *As the immediate influence of heat, on the main Spring*, tends to diminiſh the maintaining power (497), and its influence on the oil applied to the pivots, to increaſe it (498), thoſe two errors muſt, at leaſt in part, correct each other: and the effect that any remainder thereof would have on the meaſure of time, may be totally annihilated, by conſtructing the pallets, ſo that the *maintaining power*, ſhall prolong the time of one half the Vibration, as much as *it* contracts the other. *Of which hereafter*,

Influence on the Ballance and Spring.

500. *Heat* lengthens the Ballance Spring, and enlarges the diameter of the Ballance, both which effects co-operate in making the Watch go

Of the Thermometer.

ſlower; and the contrary; and as thoſe effects are wholly independent of the pallets, they muſt be corrected by ſome other means.

The time of Vibration does not depend on the whole length of the Ballance Spring.

501. *The time of Vibration of a Ballance depends* (c. p.) on the length of *ſuch part* of its Spring as acts in the Vibration, without regard to its whole length: and therefore, if the ſame cauſe, that enlarges the diameter of the Ballance be made to ſhorten the acting part of the Spring in a due proportion; and the contrary; the times of Vibration will remain the ſame.

Introduction to the deſcription of the Thermometer.

502. I ſhall therefore here deſcribe one method of adjuſting the length of the Spring to the diameter of the Ballance, in ſuch manner, as will render the times of Vibration equal, *without regard to the degree of heat or cold* to which the Watch is expoſed: and though the THERMOMETER here to be deſcribed, is adapted to an uncommon conſtruction of a Watch, wherein the Spring lies above the Ballance; when the principle is properly underſtood, the ingenious mechanic will eaſily diverſify the contrivance, ſo as to ſuit his particular purpoſe.

PLATE XIV.

Deſcription.

503. Fig. 1. Plate 14. is a ſteel ring with ſeveral pins to it; on which are fitted as many ſmall rollers as repreſented in Fig. 2; to this ſteel ring is ſcrewed one of braſs, cut as repreſented in the ſame Figure, and made by its elaſtic force to preſs againſt each of the ſmall rollers, which limit the extent of its circumference.

OF THE THERMOMETER.

504. Now as the expanſion of braſs exceeds that of ſteel, it is evident, that any heat applied to this double ring, will bring the ends of the braſs ring nearer to each other; and cold will have a contrary effect: and ſince the one end is ſcrewed to the ſteel, its exceſs of expanſion or contraction will become very ſenſible at the other end; and may be aſcertained to a nicety, by applying a ſlender Index, as repreſented by the dotted lines in Fig. 2. And

PLATE XIV. FIG. 2.

505. If this braſs ring be made to act on the one end of a lever (moving concentric to the Ballance), and to the other end of which, the ballance Spring is attached (as repreſented in Fig. 3.); the expanſions and contractions of the braſs ring may be made to move the Ballance Spring between two pins, ſo as to limit its action in ſuch manner as will render its exertion, in all caſes, proportioned to the diameter of the Ballance, and by ſuch means, render the Vibrations (ſo far as depends on this cauſe) iſochronal: The lever on which the braſs ring acts, and to which the Ballance Spring is attached, together with the Ballance Spring, and the pins which limit its action, are repreſented by Fig. 4. detached from all the other parts; and thoſe pins may be rendered moveable, ſo as to regulate the Watch, without any how hurting the effect of the Thermometer.

FIG. 3.

FIG. 4.

Of the Thermometer.

506. Fig. 5. repreſents a method of increaſing or diminiſhing the influence of the Thermometer (without ſtopping the Watch), till the performance in different degrees of heat and cold, prove it equal to its intended purpoſe: here the braſs ring (503), acts on the lever to which the Ballance Spring is connected, *by means of another lever*, whoſe center of motion is moveable by the ſcrew at A, ſo as to alter the effect, at pleaſure.

PLATE XIV.

507. Fig. 6. with its appendages, repreſent ſeparately, and in different views, the levers, &c. of which Fig. 5. conſiſts (excepting the parts repreſented by Fig. 2.) — Fig. 7. is a ſection of Fig. 5. along the line A B.

PLATE XIV.

Advantages of this Thermometer.

508. The advantages of this Thermometer are, that as all parts, of the ſurface of the braſs ring are fully expoſed to the ſame air, that influences the Ballance and its Spring; it will be influenced thereby, at the ſame inſtant with them: and, if it be made of *a mean thickneſs between that of the Ballance and its Spring*, with proper allowance for the greater motion of the Ballance*; the influences of heat and cold on it, will *exactly keep pace with*, and *equal* thoſe on the Ballance and its Spring: which can never happen with Thermometers, that only expoſe

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* See the properties of Clock Thermometers (328, to 331).

part of their ſurface to the air, and are ſo connected with larger maſſes of metal, that they can only be heated or cooled with them; and conſequently, cannot apply the remedy before the evil has had its effect, at leaſt for ſome ſhort time. And,

Advantages of this Thermometer.

509. The performance of ſuch Thermometers will alſo be leſs liable to decay, through courſe of time, than in ſuch as have not all the parts of their metal, equally compreſſed or relaxed by any changes that may happen in the temperature of the air. And,

Influence of the air on the time of Vibration.

510. As the different denſities of the air, have a tendency to alter the length of Vibration, and by that means introduce ſuch remains of error as may yet take place, from a want of abſolute natural iſochroniſm in the Ballance Spring: it is proper here to obſerve, that as ſuch *denſity of the air* depends in a great meaſure, on the degree of heat or cold; its influences on the times of Vibration muſt have an uniform tendency, either to increaſe or diminiſh ſuch errors as ariſe from the influence of heat and cold on the Ballance and its Spring: and conſequently while ſuch error is in any degree ſenſible, it may be corrected by the Thermometer (506.)

Concluſion.

511. FROM ALL WHICH IT WOULD APPEAR; *that the influences of heat and cold, may be very nearly, if not altogether as much corrected in Watches*

INFLUENCE OF THE OIL.

Watches as in Clocks * ; and the exertion of the Ballance Spring made to preſerve the ſame proportion to the *vis inſita* of the Ballance, as much as the exertion of gravity does to the *vis inſita* of the Pendulum ; and conſequently the Vibrations of the *former* be rendered as iſochronal as thoſe of the *latter*.

512. I now come to conſider, *ſeveral articles relative to the nature of pallets*, that may yet tend to influence the times of Vibration ; *and to point out reaſons* why Watches conſtructed on the horizontal principle, muſt in their *preſent ſtate*, perform much worſe than contrate wheel Watches. *if the principle of the former was only equal to that of the latter*.

Influence of the oil, &c.

513. It was formerly obſerved, that, *the influence of heat and cold on the oil*, was of a moſt pernicious nature, as no remedy could be applied by an oppoſition of the expanſion of metals (155) ; *I therefore ſhall enquire* into the comparative degree in which *this influence* takes place in horizontal Watches, and thoſe of the common recoiling principle.

How eſtimated.

514. It was ſhewn in the former Eſſay (168), that the influence of the oil was always *(c. p.)* as the relative velocity of the parts to which it was applied : *and hence*, how it was to be eſtimated

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* In Clocks, the influence of heat and cold may always be diminiſhed, while they remain in any degree perceptible.

Influence of the oil.

mated on each part of any machine (169); the ſame method is obſerved in eſtimating its influences in the following table, where all the comparative dimenſions of the *Pivots*, *Cylinder*, *Horizontal-wheel* and *Ballance*, are taken from an accurate meaſure of thoſe parts, by the Sector.

515. A TABLE ſhewing the comparative influence of the oil on the pivots of each wheel in a Watch, with a train of 18,000.

Wheels.	Mean ſize of both pivots.	Number of Revolutions.	Influence of the oil.
Firſt wheel	12	1	12
Minute wheel	6	4	24
Third wheel	2¼	24	56
Fourth wheel	2½	240	600
Horizontal wheel	2	2400	4800

Comparative influence on the horizontal pivots.

416. Thus it appears, that the influence of the oil on the horizontal wheel pivots *alone*, is ſix times as great as on *all the others taken together:* therefore, if the influence on all the pivots be expreſſed by 7, that on the horizontal wheel will be 6; and the influence on all the others, *One* (515): And,

Influence of the Ballance pivots.

517. Becauſe the horizontal wheel has 15 teeth, and *every tooth* has its puſh at *each edge* of the cylinder, it follows, that 30 Vibrations of the Ballance will be performed, for every revolution

INFLUENCE OF THE OIL.

volution of the wheel: and if, at a medium, we ſuppoſe the Ballance to move one third of a turn at each Vibration, *the motion of its pivots*, in 30 Vibrations (or one turn of the wheel), will be equal to *Ten entire revolutions*. Therefore,

To that on all the others in a Watch, as 7 to 1.

518. If the pivots of the Ballance, had been of equal ſize with thoſe of the horizontal wheel, *the influence of the oil on the former*, would be to that on the *latter*, as 10 to 1; but the diameter of the Ballance-pivots, are to thoſe of the wheel, only as 3 to 4; and conſequently, the influence on the former will only be to that of the latter, (in round numbers), as 7 to 1. And

Comparative, on all the pivots of horizontal Watches.

519. The comparative influence on all the pivots of a Watch, may be expreſſed as follows.

On the pivots of the	1, 2, 3 and 4 wheels together	1
	Horizontal wheel — —	6
	Ballance — —	42
On all the pivots together.	—	49

Influence increaſed by a recoil.

520. And as the ſizes of the pivots, and number of revolutions, are the ſame in contrate wheel Watches, as in horizontal ones with the ſame number of beats; the influences of the oil would be equal on the pivots in each, *if no recoil took place*: but let us on account of the recoil (or retrograde motion) ſuppoſe the influence on all the pivots of the wheels in the contrate Watch

INFLUENCE OF THE OIL.

to be doubled; then will the *total influence* of the oil on ſuch a Watch be expreſſed as below: *for no oil is applied to its pallets.*

On the pivots of	The firſt 4 wheels	2
	The Ballance wheel	12
	The Ballance as formerly	42
	Total	56

On contrate wheel watches.

521. *And thus it appears*, that the total influence of the oil on all the pivots of a contrate wheel Watch, is greater than in a horizontal Watch: *but in the latter*, oil is applied to the cylinder, the influence of which is yet to be added to that of the pivots.

Influence on the edges of the cylinder, &c.

522. The influence of the oil on the *acting part* of the horizontal wheel, (i. e. *on the edges of the cylinder)*, will be, to the influence on its pivots, at leaſt as the diameter of the wheel to that of its pivots (172); *or nearly as* 67 *to* 1; and conſequently, if the influence on all the pivots be expreſſed as formerly by 49 (519), the influence on the edges of the cylinder will be 402. And,

523. If the Ballance be ſuppoſed as formerly (517) to vibrate $\frac{1}{3}$ of a turn; the influence of the oil on the circular part of the cylinder, will at leaſt equal that on its edges; and conſequently may at a mean be expreſſed alſo, by 402: *and the*

whole influence of the oil on a horizontal Watch, as now conſtructed, will be as follows.

INFLUENCE OF THE OIL.

On all its pivots	—	—	49
On the cylinder	—	—	804
		Total	853

Comparative on horizontal and contrate wheel Watches.

524. The whole influence of the oil in contrate wheel Watches, has already been ſtated at 56; *therefore*, the comparative influences on *horizontal* and *contrate wheel* Watches are as 853 to 56, *or nearly as* 15 *to* 1. HENCE, if the horizontal principle, was *only equal* to that of contrate wheel Watches with recoiling pallets, in all other reſpects, the errors in the performance of horizontal Watches, would be to the errors in contrate wheel Watches, as 15 to 1; *but experience proves the contrary*; and therefore, when the influence of the oil is rendered *equal in both*, the performance will clearly prove the ſuperiority of the horizontal principle.

How diminiſhed on the cylinder.

525. It is evident, that the influence of the oil on the cylinder is *(c. p.)* as *its diameter* (168): and as *it* may be diminiſhed, by reducing the ſize of the horizontal wheel, or by increaſing its number of teeth; *let us enquire into the particular advantages of each method.*

As the diameter of the wheel.
PLATE XV.

526. FIRST, let the diameter of the wheel be diminiſhed, as repreſented at E, 4, 2, 1, Plate

INFLUENCE OF THE OIL.

15. then the cylinder, *and conſequently* the influence of the oil on it, will be diminiſhed in the ſame proportion; for the cylinders bear the ſame proportion to each other, as the wheel to which they are ſeverally adapted; (as expreſſed by the numbers annexed) *. But

Friction not altered.

527. In this caſe, the friction, and conſequently the danger of tearing the cylinder, remains unalterably the ſame; for the preſſure of the tooth on the cylinder is increaſed, as the length of the tooth diminiſhes: as may eaſily be conceived by viewing Plate 15. at E, where the preſſure is, *(c. p.)* inverſely as the diſtance of each tooth from the center of motion; i. e. *inverſely as the diameter of each Wheel.*

Inverſely as the number of teeth.

528. Let us then ſuppoſe, the number of teeth in the horizontal wheel increaſed; it is plain, that the length of each muſt be diminiſhed as their number increaſes: and the diameter of the cylinder will alſo be diminiſhed as the length of

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* The Figure in Plate 16. repreſents the manner in which the horizontal wheel acts on the cylinder; for when the tooth B has done acting on the edge of the cylinder, the tooth C drops on its outer circumference, on which it reſts, till the Vibration is performed, and the other edge of the cylinder comes within its ſphere of action; when it will begin to act wedge-like, and continue till the edge of the cylinder gets without the external dotted circle, when the tooth will drop on the inner circumference, as repreſented by the dotted lines, (and by the cylinder at D); and thus it continues to act on the edges, and reſt on the circumference of the cylinder alternately.

INFLUENCE OF THE OIL.

of the teeth ; and therefore, (522, 525), the influence of the oil on the cylinder, will be diminiſhed in each Vibration, as the number of teeth increaſes. *And*

Friction in each Vibration diminiſhed in the ſame proportion.

529. The friction in this caſe, is alſo diminiſhed in each Vibration, in the inverſe proportion of the number of teeth: *for the joint friction of any number of ſmall teeth*, rubbing on the edges of the cylinder, *(c. p.)* will be equal to *the friction on one tooth*, *that ſubtends the ſame angle at the center of the wheel* (527): See Plate 15. E 4; and the friction on the circular part of the cylinder, is diminiſhed in the ſame proportion as that on its edges (528); *therefore*, the total friction, as well as influence of the oil on the cylinder *in each Vibration*, will be inverſely as the number of teeth in the horizontal wheel: *from which it naturally follows*, *that*

Advantages of this method.

530. *The train of a Watch may even be doubled*, without any how increaſing friction or influences of the oil on any part of the Watch; *the Ballance pivots excepted:* and thus may heavy Ballances and ſtrong Ballance Springs be introduced, without the riſk of ſetting, or danger of tearing the cylinder, any more than with a common train (471), &c. Or,

531. *If the train remain the ſame*, the influence of the oil and friction, will be diminiſhed in every part of the Watch (Ballance pivots excepted) as the number of teeth of the horizontal

wheel increaſes: thus, if the number of teeth in the horizontal wheel be doubled, and the train remains the ſame; the influence of the oil on the cylinder will be reduced to a half (529); and the revolutions of all the wheels, and conſequently the friction, and influence of the oil on all the pivots, *will undergo an equal diminution.* Or,

532. If the train and number of revolutions of each wheel, be continued the ſame; the leaves of the pinions may be increaſed in the ſame proportion as the teeth of the *horizontal wheel*; and this will increaſe the action of *that* wheel on the cylinder; and conſequently enlarge the Vibrations, as well as diminiſh the influence of the oil on the cylinder (529) *.

Concluſion.

533. *From all which conſiderations it appears*, that it is much more advantageous to increaſe the number of teeth of the horizontal wheel, than to diminiſh its diameter.

Inconveniencies of the horizontal wheel now uſed.

PLATE XV.

534. In the horizontal wheel now univerſally uſed, each tooth is formed into an inclined plane or wedge, as repreſented in Plate 15. which acts on the edges of the cylinder, and by that means maintains the Vibrations; and theſe teeth

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* The friction, and irregularity of action in pinions, are diminiſhed as the verſed ſines of the angles ſubtended by their leaves: thus, the friction and irregularities of action in a pinion of 6, is to that in a pinion of 9, as 2 to 1 nearly; and to that in one of 12, nearly as 4 to 1.

after performing their office, reſt alternately on the *internal* and *external* circumference of the cylinder; *and therefore*, the friction and influence of the oil on the cylinder, during the time of reſt of the wheel, will *(c. p.)* be as the *mean circumference* of the cylinder.

535. But the inſide diameter of the cylinder, muſt be ſomewhat more than the length of the tooth, and the outſide will be yet increaſed by the neceſſary thickneſs of the cylinder; therefore its mean diameter cannot with this conſtruction of a wheel be reduced to ſuch a degree as will render the application of oil unneceſſary. But,

How remedied.

536. If the cylinder be made ſo thick as to admit of having that inclination formed on its edges, which is now formed on the face of the tooth; the teeth may then be made ſtraight without any wedge, and of the ſize of a ſmall needle; and this will admit of an equal diminution of the inſide diameter of the cylinder, which will occaſion a proportional decreaſe of friction, during the reſt of the wheel thereon. And,

Reſt performed on the inſide of the cylinder.

PLATE XVI.
FIG. 1.

537. *If the teeth of ſuch wheel*, be formed alternately on *each ſide thereof*, (as in Fig. 3. Plate 16.) they may always be made to reſt on the inſide circumference of the cylinder, thus reduced (comparatively to a point); and by this means, the friction on the cylinder, during the time of reſt, will be ſo much reduced, as not to require

the application of oil; nor will the application of it, during the time of action of the wheel, be more neceſſary here, than in the common recoiling pallets.

Advantages of ſuch alteration, &c.

538. And this will improve the performance, not only by removing the influence of the oil from the cylinder, ſo as to bring horizontal Watches in that reſpect, on a par with thoſe of the common conſtruction (524); but alſo by diminiſhing the friction on the cylinder, ſo as to make the ſame maintaining power ſupport a much longer Vibration; *the advantages of which* have already been conſidered (488), 489).

Concluſion.

PLATE XVI. Fig. 1.

539. And if ſuch a horizontal wheel, as here deſcribed and repreſented in Plate 16. Fig. 1. be made of well tempered ſteel, and the parts of action of the cylinder of ſteel thoroughly hard, or diamond, the performance of ſuch machine, will prove the ſuperiority of the horizontal principle to any other.

Any power co-operating with the Ballance Spring, will accelerate the Vibrations.

540. Since the ſpiral Spring *promotes the motion of the Ballance towards its point of reſt*, and *oppoſes its receſs therefrom*; it is plain, that if any other power be made to act on the Ballance *in the ſame manner*, it will have a ſimilar effect on the times of Vibration, *as an increaſe of ſtrength in the Spring would have*; i. e. it will ſhorten the times. *And*

And the contrary.

541. If the ſame power be applied, *ſo as to oppoſe the motion of the Ballance towards its point*

of reſt, and promote the motion therefrom, it will, by ſuch means, *counteract* the exertion of the Spring (411), as much as it aſſiſted in the former caſe (540); and therefore, will have a contrary effect; i. e. *it will prolong the times of Vibration*. And thus;

Thoſe effects being made equal, and contrary, will deſtroy each other.

542. If the action of the horizontal wheel, be ſo applied to the edges of the cylinder, *that it ſhall co-operate with the Ballance Spring in its unbending*, juſt as much *as it counteracts it in bending* (411), the one half of its action will *contract* the time of Vibration (540), as much as the other *prolongs* it (541); *and conſequently*, thoſe equal and contrary effects will always *ballance* each other, *and leave the whole time of Vibration the ſame*, *as if no ſuch cauſe took place*. Hence, ſuch changes as happen in the action of the wheel on the pallets, cannot alter the times of Vibration.

Illuſtrated.

543. EXAMPLE. Let there be ſuppoſed two concentric circles paſſing through the extremities of the parts of action of the horizontal wheel, as repreſented by the dotted lines in Plate 15. it is evident, that the wheel can only act on the edges of the cylinder, while they remain within thoſe circles; and if their diſtance be divided into two equal parts as at A, and another circle be drawn through that point; the edges of the cylinder when at reſt, ſhould terminate in that circle, as repreſented alſo at A; in which caſe, the

PLATE XV.

maintaining

OF PALLETS, &c.

maintaining power would prolong the time of the one half of the Vibration (542), juſt as much as it contracted the other. But,

544. If the edges of the cylinder reſt within this circle, as at G, the maintaining power will prolong the one half of the Vibration (540), more than it contracts the other (541), in proportion as the edges of the cylinder lie nearer the inner circle, than the outer; See Plate 15. at G: and conſequently, the whole Vibration will take up more time than if performed by the action of the Ballance Spring *only*; and *this effect* of the maintaining power, will become *greater* as the Vibrations become *ſhorter* (as ſhall be ſhewn hereafter), and produce the ſame effect on the meaſure of time, *as if* the ſhorter Vibrations of the Ballance, when actuated by its Spring alone, were naturally ſlower than the longer ones*: and this is the caſe in all horizontal watches; for if the edges of the cylinder were to reſt in the circle, as at A, the points of the teeth would not drop on the circular part of the cylinder, (as at C and D), but on its edge; which would check the Vibration, and produce the moſt deſtructive effect.

PLATE XV.

Length of Vibration, as the velocity at the loweſt point, &c.

545. The length of Vibration in Pendulums, *(c. p.)* depends on their velocity at the point of reſt, (i. e. at their loweſt point), and the time

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* And thus will every change in the action of the wheels, or any other cauſe that can alter the angle of Vibration, alſo alter the times.

of the ſubſequent aſcent will be the ſame, whether ſuch velocity was the *ſole effect* of GRAVITY, or the *joint effect of* IT *and the action of the wheels* in the preceding deſcent *; and the time of the ſubſequent deſcent cannot be influenced by the action of the wheels, before ſuch action takes place; *it therefore follows* †, That,

Influence of the maintaining power, as its time of action.

546. *The influence of the maintaining power on the meaſure of time*, is, *(c. p.) as the time of its action* (545); nor will *its* effect in maintaining the Vibrations, be any how leſſened by ſhortening its time of action ‡, and all this, as appli-

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* See Sir ISAAC NEWTON's 4th Definition, where he ſays, "An "impreſſed force remains no longer in a body, than its action "continues; for a body maintains every new ſtate it acquires "by its *vis inſita* only."

† It alſo follows, from thoſe conſiderations, that it is more adviſeable, in Clocks, to apply the action of the wheels to the Pendulum, in the time of its aſcent than deſcent; and in Watches, in the time of bending, than the time of unbending the Ballance Spring: for if ſuch action be applied in the time of aſcent, its effect on the meaſure of time ceaſes with the action; but whatever power adds to the velocity of the Pendulum, &c. in its deſcent, will influence the time of all the ſubſequent part of the deſcent: and for the ſame reaſon, it will hurt the performance, to make the maintaining power act more *vigorouſly* at the beginning than towards the end of deſcent. (See the Notes to 226.)

‡ See Sir ISAAC NEWTON's Second Law of motion; where he ſays, "If any force generates a motion, a double force will "generate a double motion, a triple force a triple motion, "whether that force be impreſſed altogether and at once, or "gradually and ſucceſſively." I have already (440) endeavoured to ſhew how the bad effects of the *vis inertiæ* of the wheels are to be diminiſhed, and therefore take no notice of it here.

cable to the Vibrations of the Ballance, as thoſe of the Pendulum (413).

Principle on which the maintaining power cannot alter the time of Vibration.

547. *And thus*, by making a horizontal wheel that will act on the cylinder, *juſt as much* in the time of *bending the Ballance Spring*, as in the time of *its unbending* * ; the maintaining power may be made to prolong the time of one half the Vibration (541), as much as it contracts the other (540) ; and *if the leaſt defect yet remains* owing to the execution, &c. *its effect* may be diminiſhed by ſhortening the time of action of the wheel on the cylinder (546); and by thoſe joint means, the performance may be rendered more compleat IN WATCHES (ſo far as depends on the maintaining power), *than in Clocks where the influence of the oil takes place* †. But,

Introduction to further conſiderations, &c.

548. Having already ſhewn reaſon (544), why all horizontal watches hitherto made, or that can be made, with the wheel and cylinder, now in uſe, muſt have their Vibrations ſomewhat ſlower than if the Ballance was actuated by its Spring alone : and why this effect muſt become

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* That is, that the action of the wheel on the Ballance be equally applied on each ſide the point of reſt; or that the wheel act as much on the *Ballance* in the time of *its* approach to its point of reſt, as in the time of its receſs therefrom.

† Here it is to be noted, that as the influences of heat and cold on the oil, main Spring, and Fuſee, only tend to increaſe or diminiſh the *maintaining power*, their effects on the times of Vibration are totally removed by this method of applying *it* to the Ballance.

greater in the ſhorter Vibrations, than in the longer ones (546) *. I now come to a more particular conſideration of a wheel and pallets, that will admit of removing this defect, as well as the influence of the oil; *and by that means leave the Vibrations of the Ballance and Spring in full poſſeſſion of all their natural properties.*

Deſcription of a new ſcapement.

PLATE XVI.

549. Fig. 1. Plate 16. repreſents a ſcapement conſiſting of one pallet and a detent, by means of which the wheel acts on the Ballance, at *every ſecond Vibration only*; this ſcapement, if judiciouſly executed, will have the properties formerly mentioned (547), and admit of very quick Vibrations, as the time of action of the wheel bears ſo ſmall a proportion to its time of reſt; and the inſide diameter of the detent and pallet may be made ſo very ſmall (in proportion to the mean diameter of common cylinders), as almoſt to annihilate friction, and the influences of the oil during the time of reſt (526); by which means, the Vibration will be much increaſed; *and hence*, a double advantage acquired, even though the uſe of oil ſhould yet be found neceſſary †.

Uſes of this ſcapement.

550. This ſcapement will alſo ſerve *to prove experimentally*, what has been ſaid concerning the

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* For which reaſon every cauſe that can alter the length of the Vibrations, will alſo alter their times.

† In this ſcapement all the teeth of the horizontal wheel ſtand on one ſide, as repreſented by Fig. 2.

nature of ſcapements (540, 541), and how much the effects of the maintaining power on the times of Vibrations of different lengths, *have hitherto been miſtaken for the natural tendency of the Ballance and Spring.*

Experiment.

Longer Vibrations rendered quickeſt.

PLATE XVI.

551. If the pallet be in the poſition repreſented at A, Fig. 1. when the Ballance is at reſt, *the action of the wheel will tend to prolong the time of Vibration* (541); and this effect will be greateſt on the ſhorter Vibrations (546); hence, if the natural tendency of the Vibrations be iſochronal, the action of the wheel on the pallets will render *the ſhorter Vibrations of longer duration than the longer*; and all the Vibrations ſlower than they would be performed by the ſole exertion of the Ballance Spring.

Experiment.

Longer Vibrations rendered ſloweſt.

PLATE XVI.

552. Let the pallet be in the poſition repreſented at C, when the Ballance is at reſt; and the action of the wheel *will ſhorten the time of Vibration* (540), and render them quicker than if performed by the exertion of the Ballance Spring alone; and this accelerating effect alſo will be greateſt in the ſhorter Vibrations (546); and

conſequently, if all the Vibrations of the Ballance were naturally iſochronal, the action of the wheels would, in this caſe, render the *longer Vibrations ſlower than the ſhorter:* how abſurd then is it! to form a concluſion of the *natural tendency* of the longer and ſhorter Vibrations of the Ballance and Spring, while ſuch foreign and *unobſerved* cauſes influence them.

Experiment.

All the Vibrations have their natural properties, &c.

PLATE XVI.

553. *Laſtly*, if when the Ballance is at reſt, the pallet be in the poſition repreſented at B; the one half of the action of the wheel on the pallet will be exerted, while the Ballance Spring is *unbending*, and the other half, *while bending*; and conſequently, the former half will contract (540), as much as the latter prolongs (541), the time of Vibration, and the *whole time* will be the ſame, as if the Ballance was actuated by *its Spring alone*, without any regard to the force, with which the wheel acts on the pallet *.

How the defects of the Ballance Spring may be remedied.

554. By the above means we may *not only* diſcover the NATURAL TENDENCIES of the longer

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* The only inconvenience of this ſcapement, ſo far as occurs to me, is, that the interval between the beats will be alternately long and ſhort: but this will in no degree influence the meaſure of time, or render the Watch leſs fit for obſervations of any kind; for thoſe two beats which come cloſe to each other, may be conſidered as one.

and ſhorter Vibrations of any Ballance and Spring when no maintaining power is applied (553); *but the natural tendency being once known*, if the longer Vibrations be quicker than the ſhorter, or the ſhorter quicker than the longer, they may be corrected by altering the poſition of the pallet as already mentioned (551, 552) †.

Introduction to another ſcapement.

555. *Having pointed out the means, by which the natural properties of the Ballance and Spring may be preſerved, by a proper attention to the poſition of the pallet (where one only is uſed)* (553), *I now come to conſider the means of preſerving and recovering them, where two pallets are uſed, and the wheel acts in every Vibration.*

Deſcription, &c. of the curve of action.

PLATE XVI.

556. Fig. 4. Plate 16. ſhews the nature of the curve, into which the edge of the cylinder is to be formed: from which it appears, that *the wheel has an equal power of moving the Ballance, on whatever part of this curve it acts*; for if the cylinder be made to move through equal ſpaces, as marked on the Arc A B, the wheel will advance equal ſpaces, as marked on the line A D; and it is to be underſtood, that the ſcapement in Fig. 1. as well as the following ones, has this property.

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† And what is here ſaid, relative to the poſition of this *one* pallet, is equally applicable to each pallet, where two are uſed: and if the relative poſition of the pallets to each other could be altered, the effect would be as above ſtated.

Relative poſition of the edges of the cylinder.

557. Fig. 5. repreſents the relative poſition of both edges of the cylinder, when the wheel is made to act at each Vibration; and its teeth ſtand alternately to each ſide, as in Fig. 3. where it appears, that the ſame central angle A C B, ſubtends both the curves on the edges of the cylinder; and that thoſe curves croſs each other, exactly at half the thickneſs of the cylinder; *without which*, the natural tendency of the Vibrations will be diſturbed (553).

When the time of action ſhould be rendered long, and when ſhort.

558. Here it is to be obſerved, that as the effect of any imperfection of the maintaining power, is increaſed or diminiſhed, with the angle which the curve of action on the edge of the cylinder ſubtends at the center (546); ſuch angle ſhould be diminiſhed, where the *true meaſure of time* is the chief object of our attention; *and increaſed, where we deſire by experiments to prove, the theory of pallets and Ballance Springs* *.

Obſervation.

559. It is alſo to be obſerved, that when two pallets are uſed, (*i. e.* when the wheels acts on both edges of the ſame cylinder) the comparative times of the longer and ſhorter Vibrations, cannot be altered as with the ſcapement, Fig. 1. (551, 552).

PLATE XVI.

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* Here it is to be obſerved, that by increaſing or diminiſhing the angle ſubtended by the curve of action of the pallet, (i. e. the angle of ſcapement) the time of action of the maintaining power is alſo increaſed or diminiſhed.

Of pallets, &c.

Practice cannot, in this reſpect, equal theory.

560. If execution could be ſuppoſed equal to mathematical demonſtration, and the teeth of the horizontal wheel as fine as a mathematical line, we might in practice, as well as in theory, preſerve the natural properties of the Vibrations, by the means propoſed in paragraph (542), and repreſented by Fig. 5. But as the teeth muſt have ſome ſmall thickneſs, and we muſt carefully guard againſt their dropping on the edge (or part of action) of the cylinder, we cannot perfectly preſerve the natural properties of the Ballance and Spring, with this conſtruction of pallets; but be in a leſs degree liable to the retardation, which was ſaid to take place in the common horizontal wheel (544) *.

How thoſe inconveniencies may be avoided.

561. *I therefore come to enquire, by what conſtruction of pallets thoſe inconveniencies may be avoided, and the wheel made to act at each Vibration?* i. e. on both edges of the cylinder.

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* Mr. Lepaute, an ingenious French Clockmaker, in his Treatiſe, publiſhed at Paris 1755, deſcribes a conſtruction of pallets of his invention, in which the tooth reſts on the inſide of the cylinder at each Vibration; by which means, the friction on it, during the time of reſt, is very much diminiſhed, and conſequently a very conſiderable advantage gained. But the action of the wheel tends, in his conſtruction, to retard the Vibration, during *its whole time of action*; and this effect will always increaſe or diminiſh, in proportion to the length of Vibration, and every cauſe that can alter the length of Vibration will alter the times; nor has any attempt been ever yet made to obviate this evil, ſo far as conſiſts with my knowledge.

Conſtruction of the Figure.

PLATE XVI. FIG. 6.

562. Let us then ſuppoſe, that the curves on the edges of the cylinder, ſubtend different angles at the center, as A E B, B E C, Fig. 6. and let the dotted line E B, repreſent part of the dotted Arc which circumſcribes the points of the teeth of the wheel, as at A, Fig. 1. it is evident (551), that the whole action of the wheel on each pallet, will prolong the times of Vibration: but as the angle B K C, ſubtended by the edge of the cylinder, Fig. 7. may eaſily be known, we may find another angle E K D *, which the Ballance will be thrice as long in deſcribing: then if L G, be made equal to $\frac{1}{6}$ of F D, and *the* CURVE G F, be formed in the ſame manner as the curve A D, (or D B, Fig. 4.) *the action of the wheel* on IT will accelerate each Vibration, as much as *it* retards on the curve A D. For

Demonſtration.

563. If the power of the wheel in moving the Ballance, was as great on the curve G F, as on A D, (or A B,) the effects on each would be as the relative times of action (446); and each time of action on the curve G F, is (by the hypotheſis) thrice as long, as the time of action on the edge of the pallet A D; and the wheel acts on G F, both in the progreſs of the Ballance towards the extremity of Vibration, and in its return, where-

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* See (408), where the properties of the Vibrations of the Ballance and Spring are ſhewn to be the ſame with thoſe of a Pendulum vibrating in the cycloid, &c.

Of pallets, &c. as it acts on A D, *only once in each Vibration:* therefore, the whole time of action on G F, is to the whole time of action on A D, in each Vibration, as 6 to 1. But when a cauſe is uniformly exerted, the effect will be as the times: hence, if the wheel had the ſame power of moving the Ballance on the curve G F, that it has on A D, the acceleration on the former, would be ſix times as great as the retardation on the latter: but the power of the wheel on G F, is to its power on A D, as L G, to F D; *that is, as 1 to* 6. thereſore, *the powers being in each inverſely as their times* of action, the effects will be equal. *Conſequently*

Concluſion. 564. Whatever be the action of the wheels *on pallets of ſuch conſtruction*, it will as much accelerate (*i. e.* contract) the one part of the time of Vibration, as it prolongs the other: and the whole time of any Vibration, of whatever length, will be the ſame, *as if performed by the ſole exertion of the Ballance Spring.*

COROLLARY.

565. If the curve G F, was continued till it terminated in the center (as repreſented by the dotted line), the acceleration would conſtantly increaſe as the Vibration; but the retardation on A D, is diminiſhed as the Vibration increaſes (446);

(446); *and therefore*, ſo ſoon as the angle of Vibration becomes greater, than twice the angle E K C, the whole time of Vibration would be contracted, and that in proportion to the increaſe of Vibration: and this ſhews the neceſſity of diſcontinuing the curve F G, at G, and ſubſtituting the circular Arc G I M, which ſhould ſubtend an angle at leaſt equal to the greateſt fluctuations of the Vibration.

The ſame demonſtration would, c. p. apply to the outſide of a cylinder.

566. What is above demonſtrated of the inſide of a cylinder, is equally applicable to the outſide, as on the tumbling pallets: but as the wheel has not in them, an equal power of moving the Ballance in every part of its action, the demonſtration will not apply: it is alſo to be obſerved, that when thoſe pallets are made to have ſuch a proportion to the wheel, that its teeeh ſhall act nearly at right angles to the circumference of the cylinder, during the time of reſt, *the time of action on the pallets, will bear too great a proportion to the time of reſt* (446); by which means, the effect which any external motion or alteration in the action of the wheels, will have on the meaſure of time, will alſo be increaſed, *as well as* the chances of the Watch's ſtopping by the influence of any external motion: for which reaſons I thought it unneceſſary here, to give a particular deſcription of them; the neceſſary remarks on pallets having already far exceeded my intended limits: nor does it appear to me, that any one, who fully underſtands

But does not in the tumbling pallets.

what has been ſaid in this and preceding eſſays, can be at any loſs, in eſtimating the merits of any particular conſtruction of pallets, or in conſtructing new ones, to anſwer any particular purpoſe.

Of the Reſiſtance of the Air.

Air, its denſity does not alter the motive force of the Ballance.

567. As the times of Vibration of a *Ballance*, have no dependence on gravitation, it follows, that no alteration in the ſpecific gravity of the air, can alter *its motive force*, as it does that of Pendulums (378). *Therefore*,

Hence cannot influence the times with perfect pallets, &c.

568. Any alteration of denſity in the air, can only influence the Vibrations of a Ballance, by ſhortening the Vibration in proportion to the increaſe of denſity: nor can ſuch changes in the length of Vibration, alter its whole time any any other ways, than by introducing any remaining imperfection of the Ballance Spring or pallets; (for it prolongs one half as much as it contracts the other) (238, 129). *Hence*,

569. If the Ballance Spring have the natural tendency to perform all its Vibrations in equal times, and the pallets have the properties deſcribed (553, 564); *no alteration of denſity in the air, can any how alter the times of Vibration.* But,

In what caſes it does alter the times.

570. Admitting the natural properties of the Ballance Spring (408), if the maintaining power

has any tendency to render the times of the longer Vibrations, either quicker or ſlower than the times of the ſhorter (551, 552), and if this effect be corrected, by an unlimited recoil, (or inverted recoil), as repreſented by the dotted ſpiral line in Fig. 7. Plate 16. and deſcribed (565); I ſay ſuch being the caſe, that any change of denſity of the air will alter *the times*, as well as lengths of the Vibrations; and for this reaſon, no curve of whatever kind ſubtending the angle of fluctuations, and having a tendency either to contract or prolong the time, can ever preſerve, or recover the natural iſochroniſm of the Vibrations of a Ballance (565).

Dead-beat neceſſary.

571. *It alſo follows*, that where the natural tendency of the Vibration is iſochronal, its properties can never be preſerved without the dead-beat (565). *But*,

A good performance, with imperfect pallets.

572. If the maintaining power and angle of Vibration, be ſufficiently increaſed (487, 488, 489), and the time of action of the wheels on the pallets diminiſhed (546), and ſome regard paid to what is ſaid (540, 541), a good performance may be procured, *even with pallets of leſs perfect conſtruction.*

573. But in all caſes, where doubt or uncertainty take place, it is ſafeſt leaning to the DEAD-BEAT; for IT, *in conjunction with long Vibrations*, will always diminiſh an error of the maintaining power (263); whereas a recoil, of

any kind, may have a direct contrary effect; and therefore, like dangerous medicines, are never to be adminiſtered, unleſs where it can be done by weight or meaſure.

Concluſion.

Having thus endeavoured to ſettle practical Theory of Clock-work, and to point out the means of acquiring ſuch advantages in PORTABLE MACHINES, as may render their performance nearly equal to that of CLOCKS, even in their improved ſtate; if I have any where miſrepreſented or omitted any thing material, it was not intentionally: but granting the truth of all that I have advanced, many are the experiments and practical improvements that may yet be made, towards confirming this Theory, and rendering it of general utility. And ſhould this be thought an object worthy of public attention, I ſhall chearfully contribute my utmoſt endeavours.

THE END.

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A.

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G.R III

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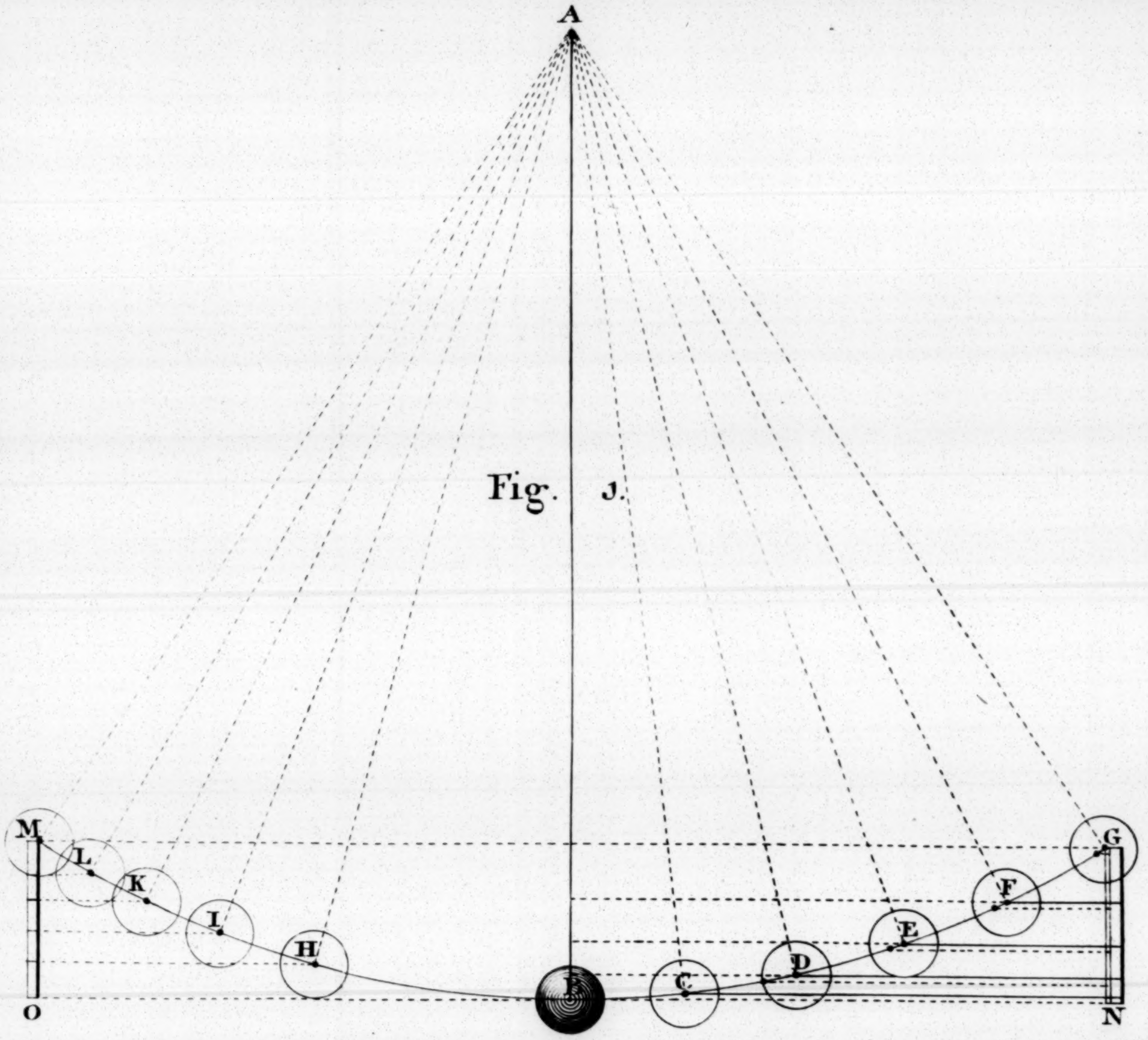

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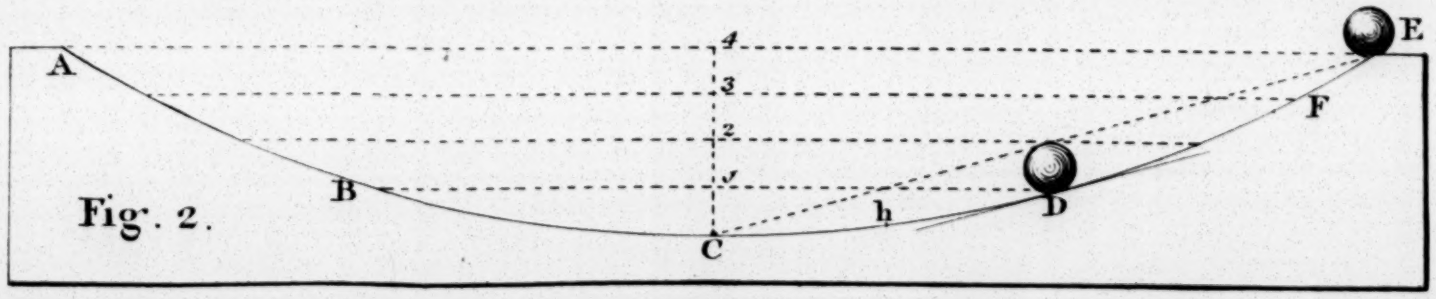

Fig. 2.

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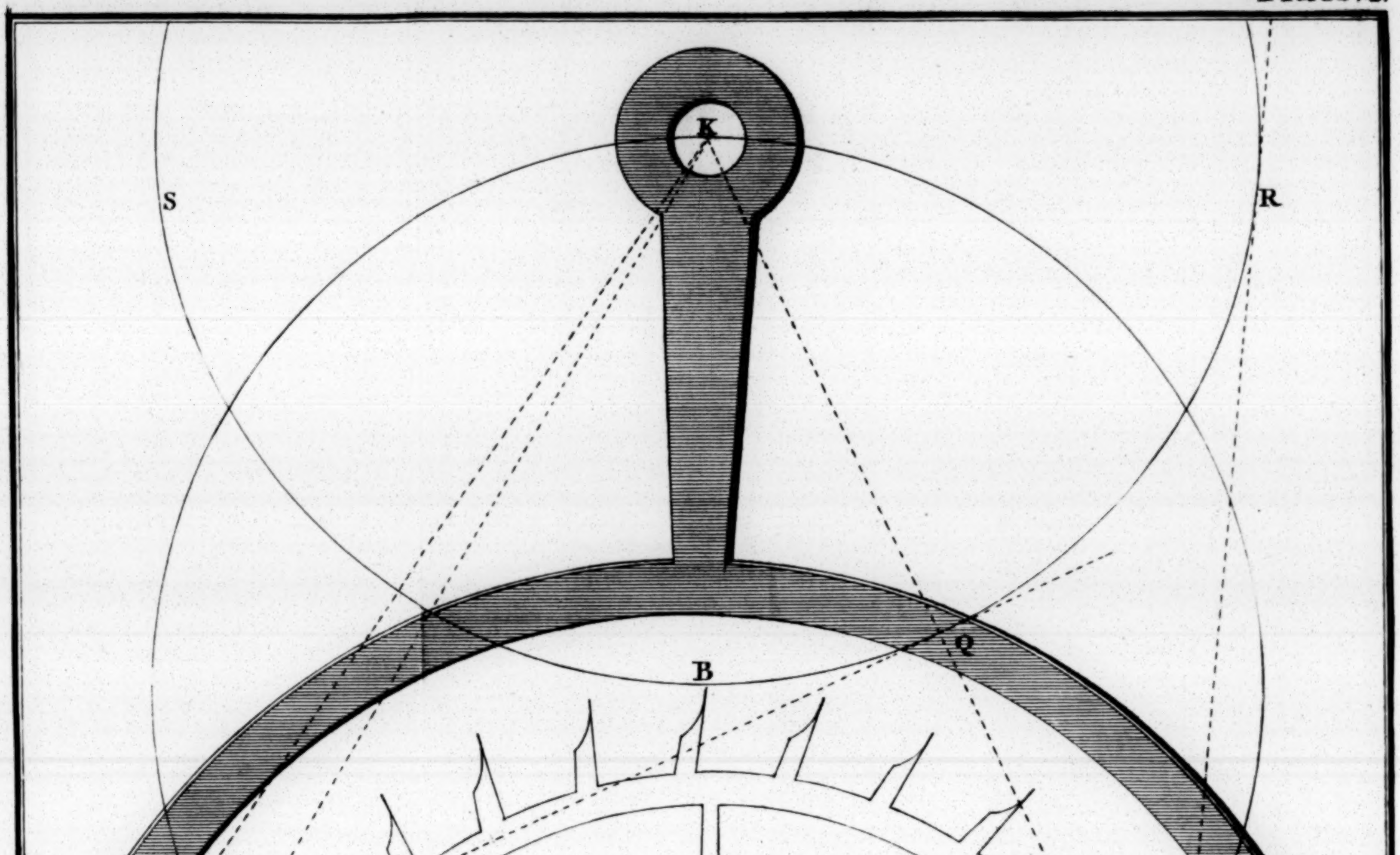
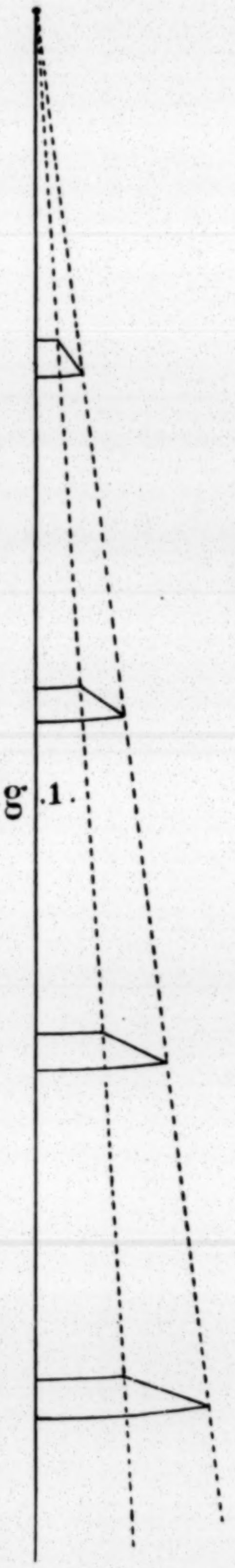


A. Cumming inv. & delin.

J. Miller Sculp.

Plate.3.



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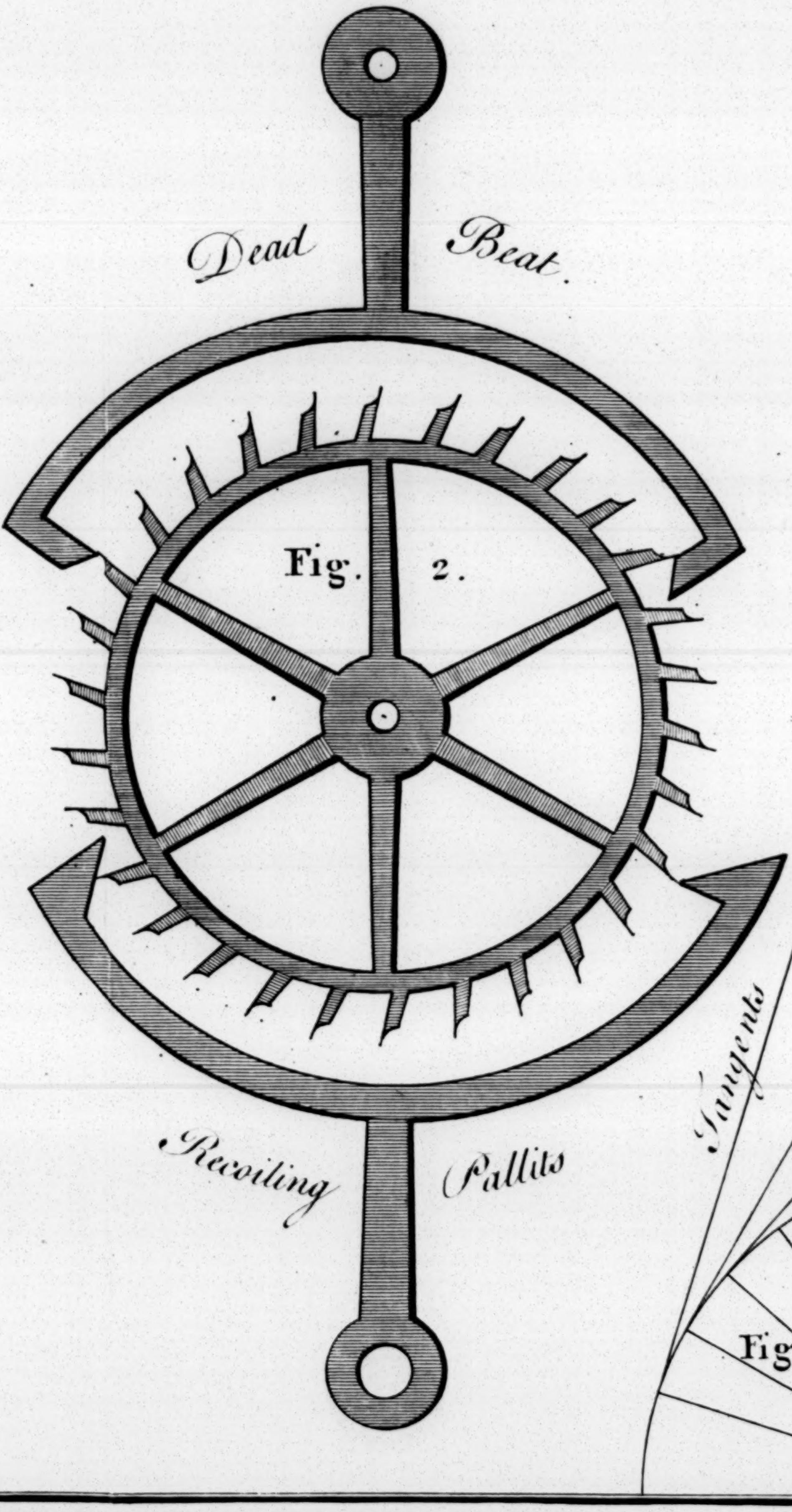

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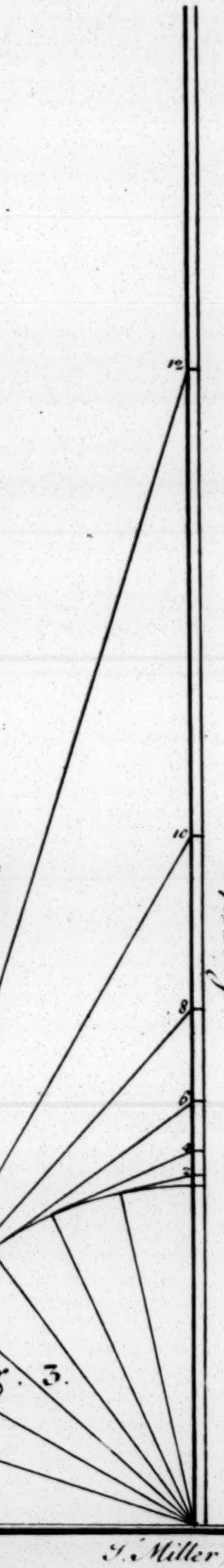
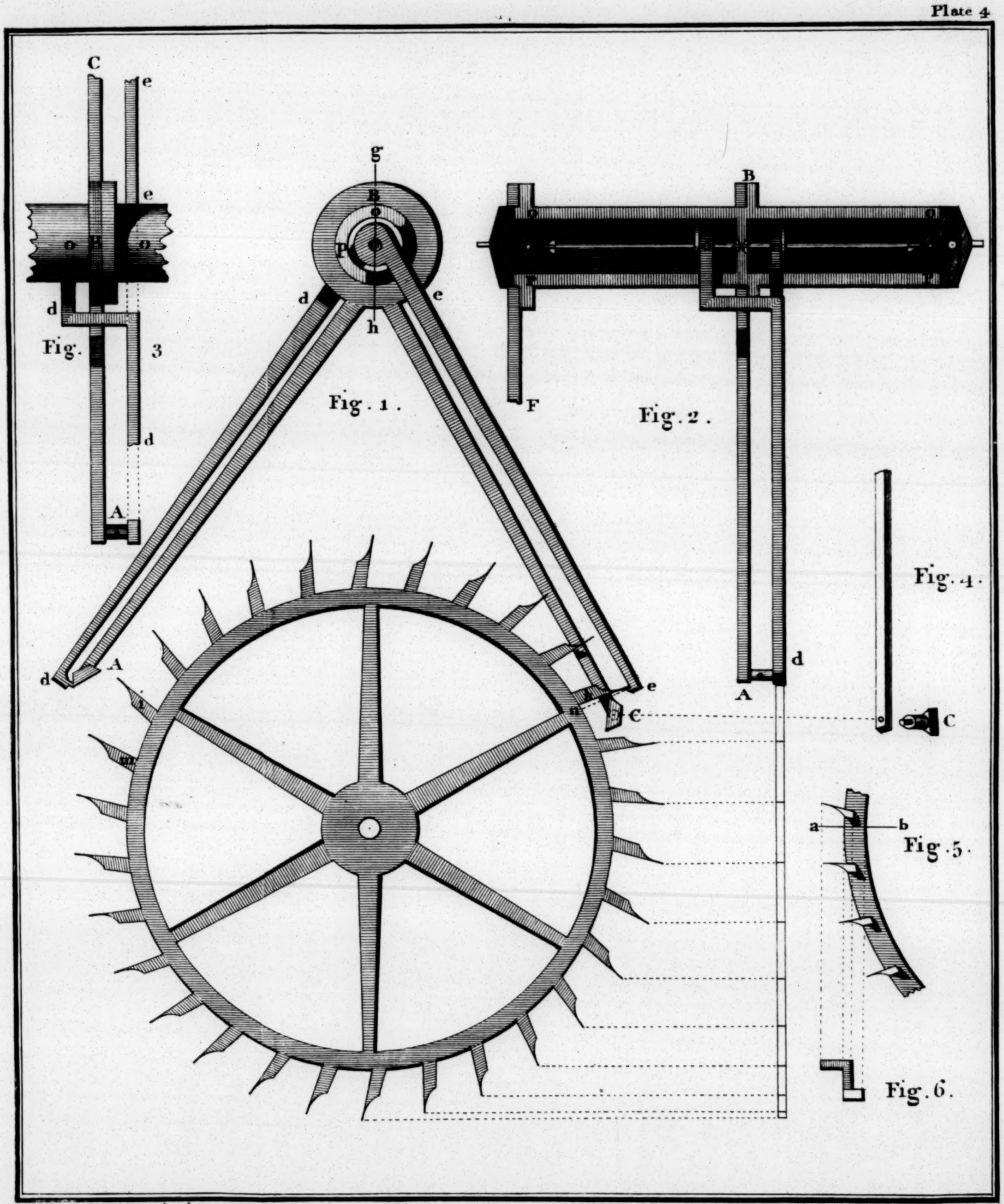


Fig. 3.

A. Cumming inv: & delin.

J. Miller Sculp.

Plate 4



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T. Miller sculp.

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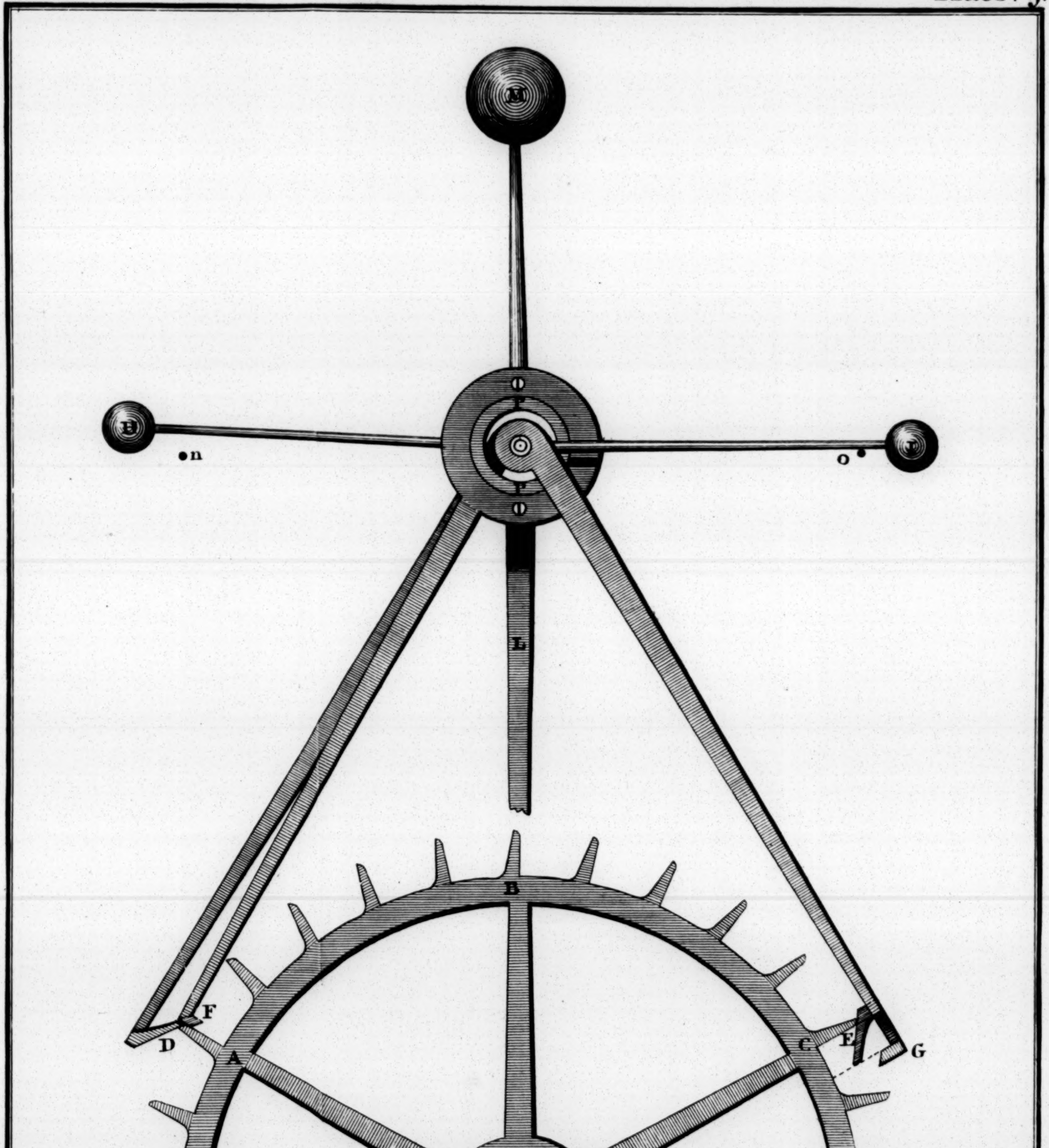

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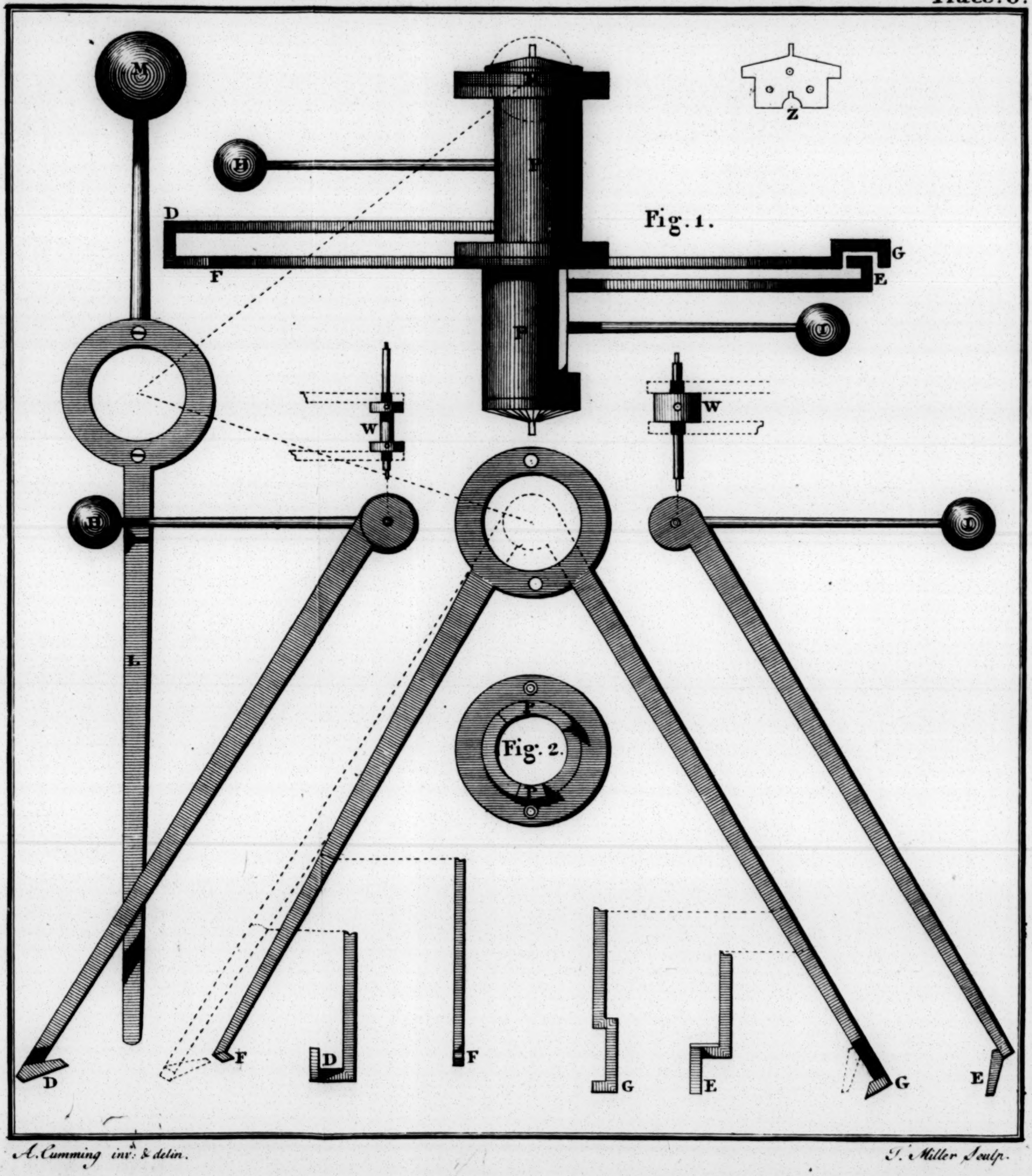

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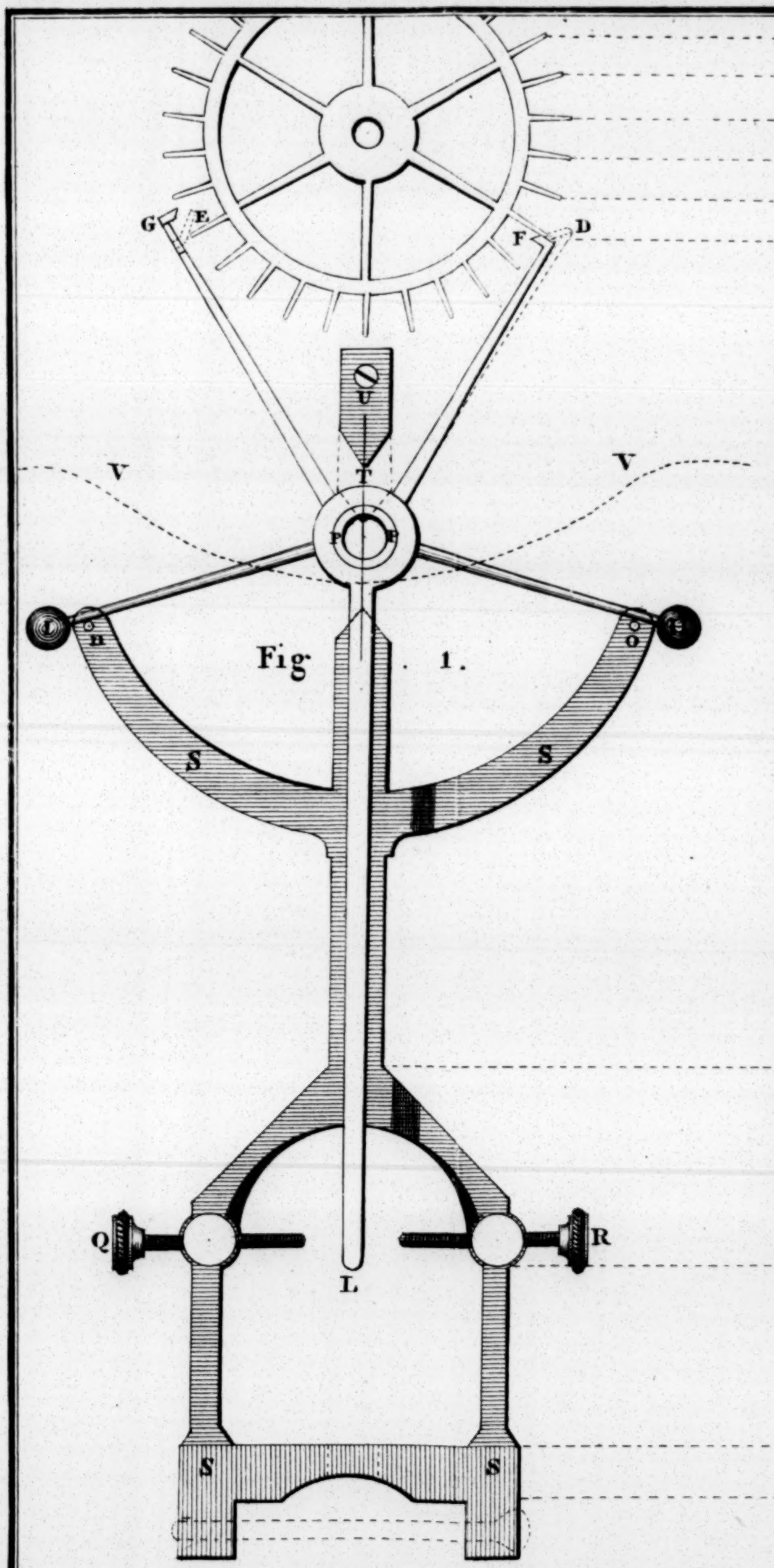

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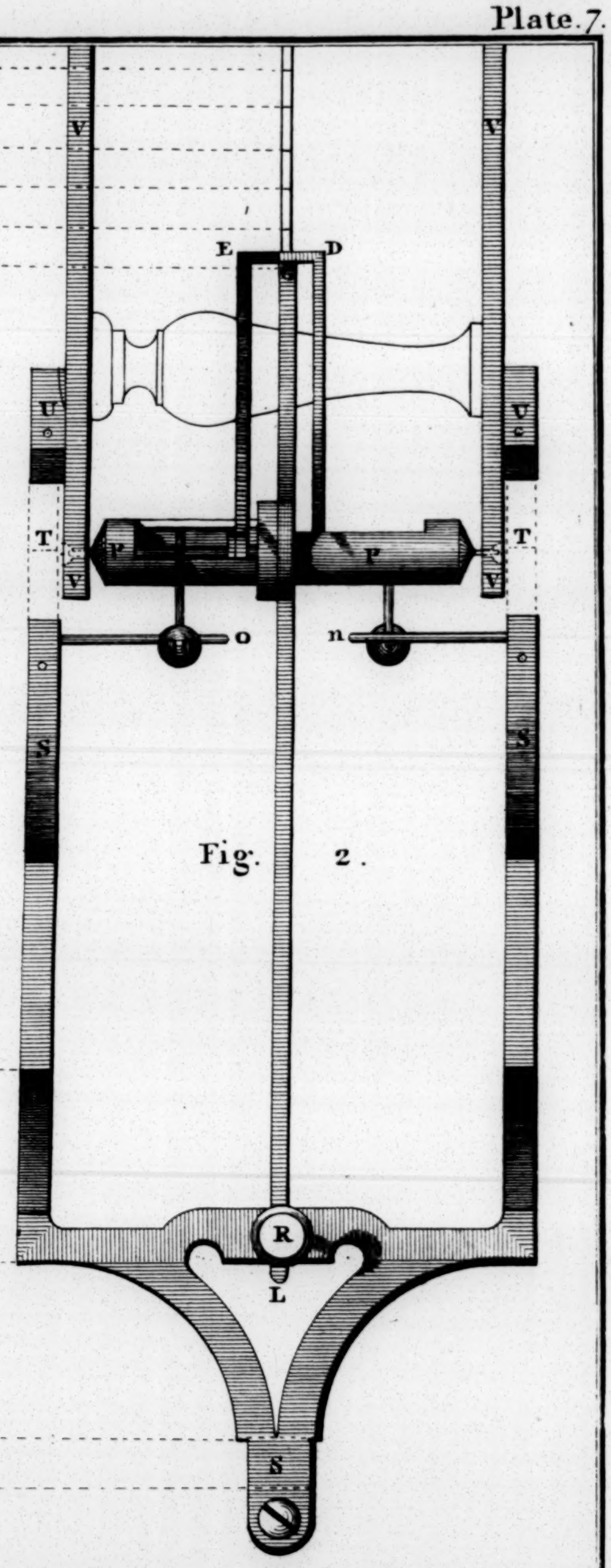
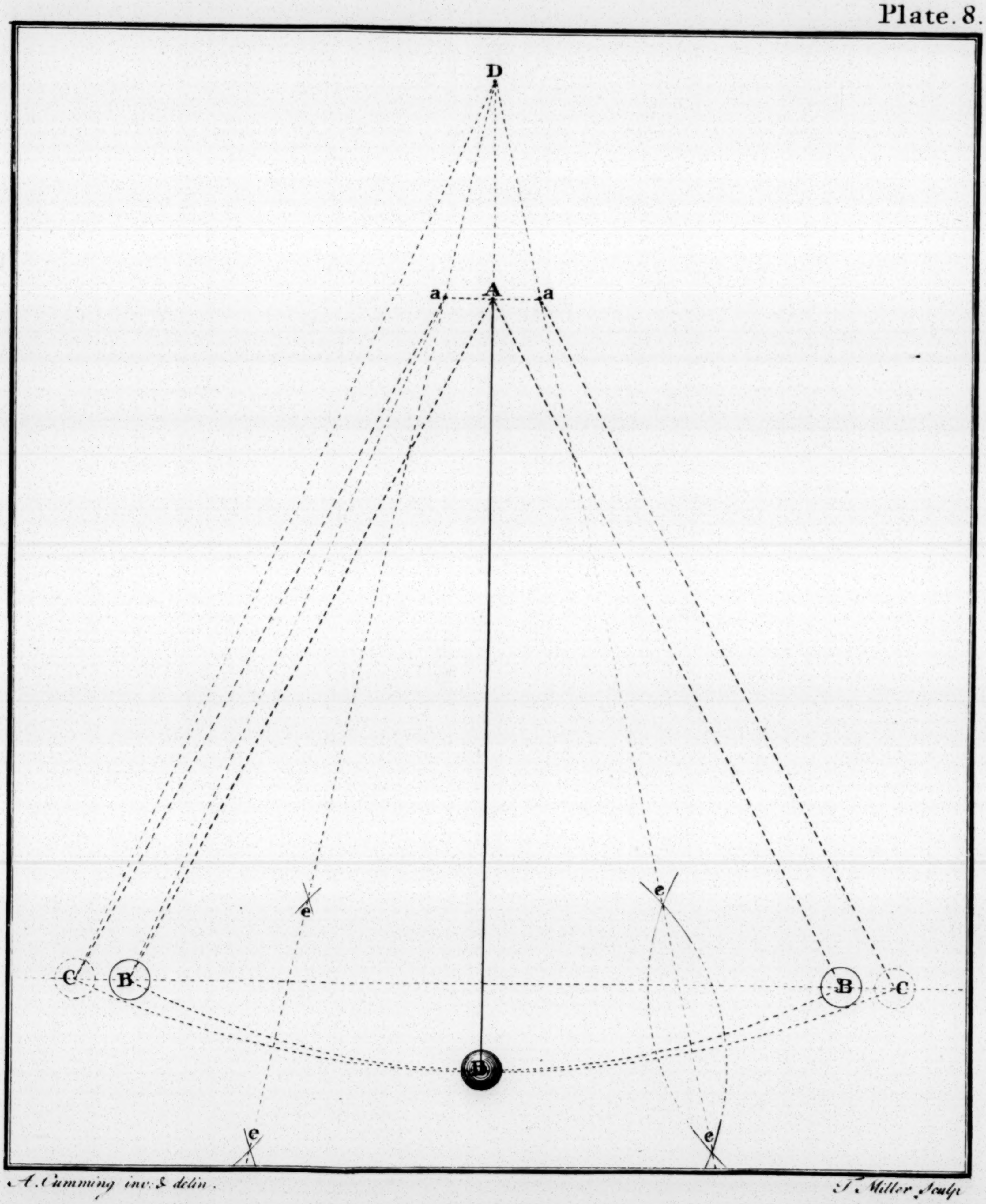


Fig. 2.

A Cumming delin.

J. Miller Sculp.

Plate. 8.



A. Cumming inv. & delin.

T. Miller Sculp.

Plate. 9.

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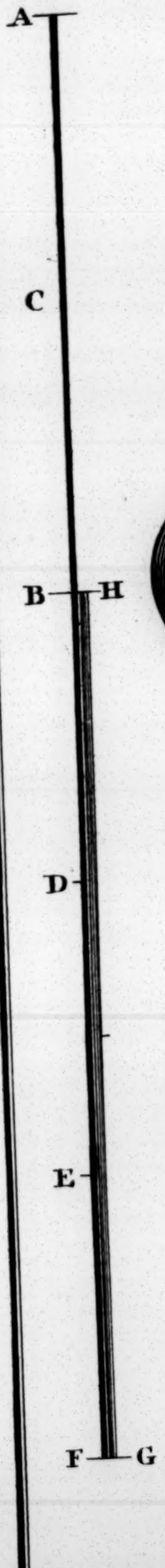

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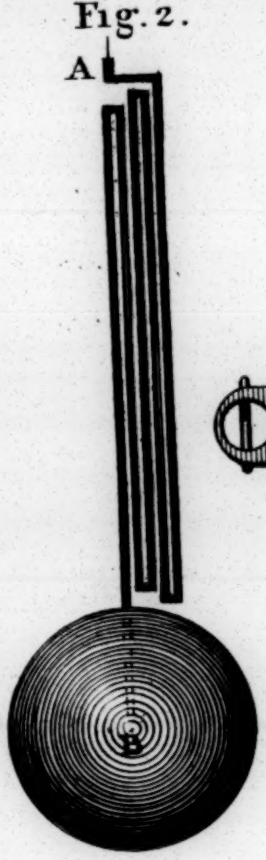

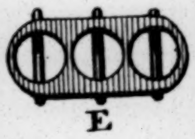

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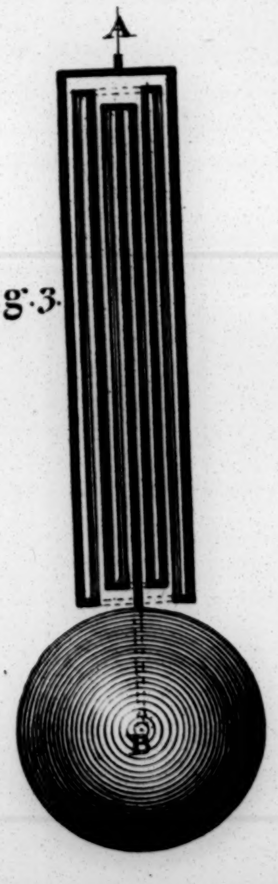

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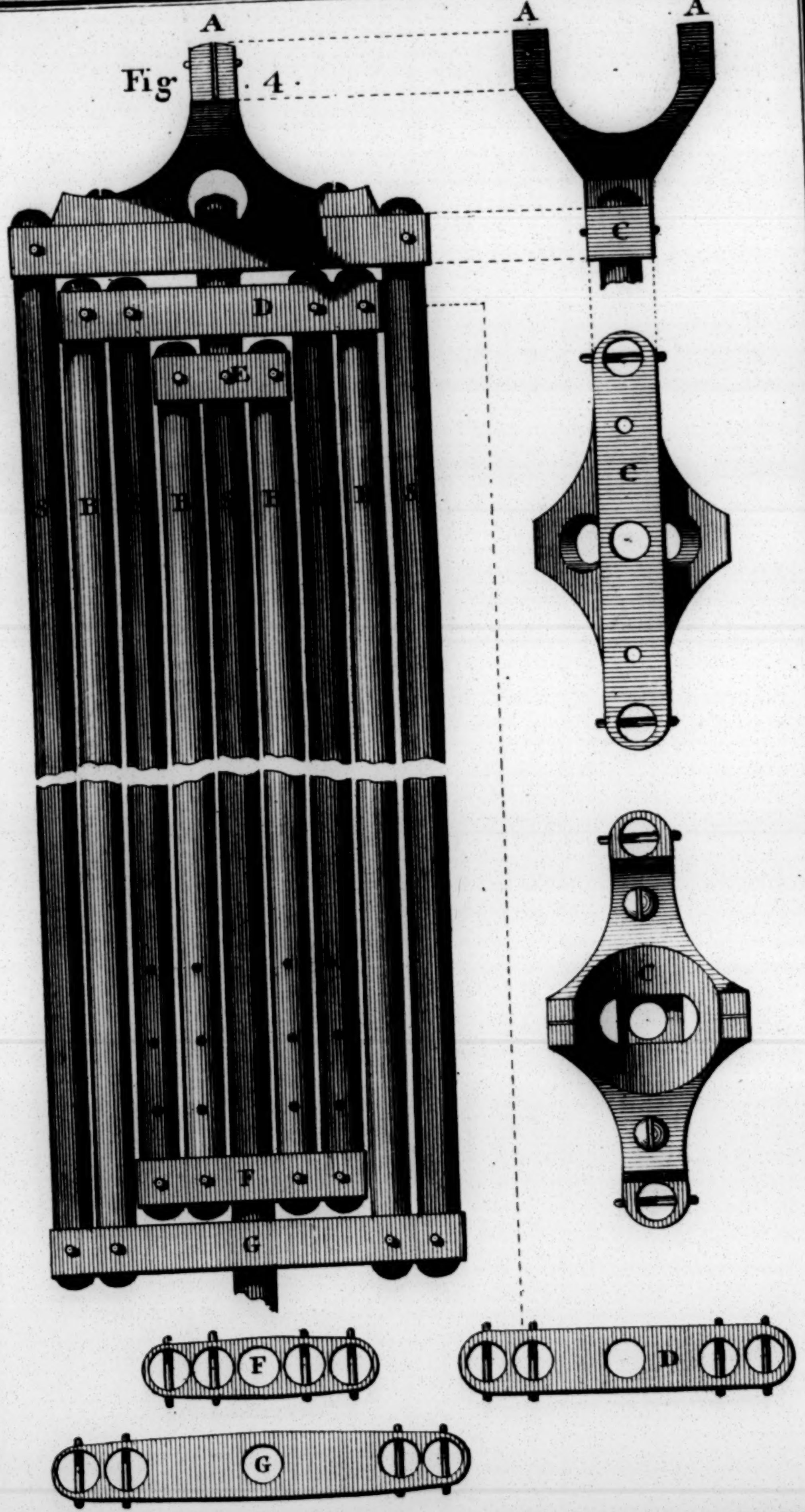

A. Cumming delin.

J. Miller Sculp.

Plate. 10.

Fig. 3.

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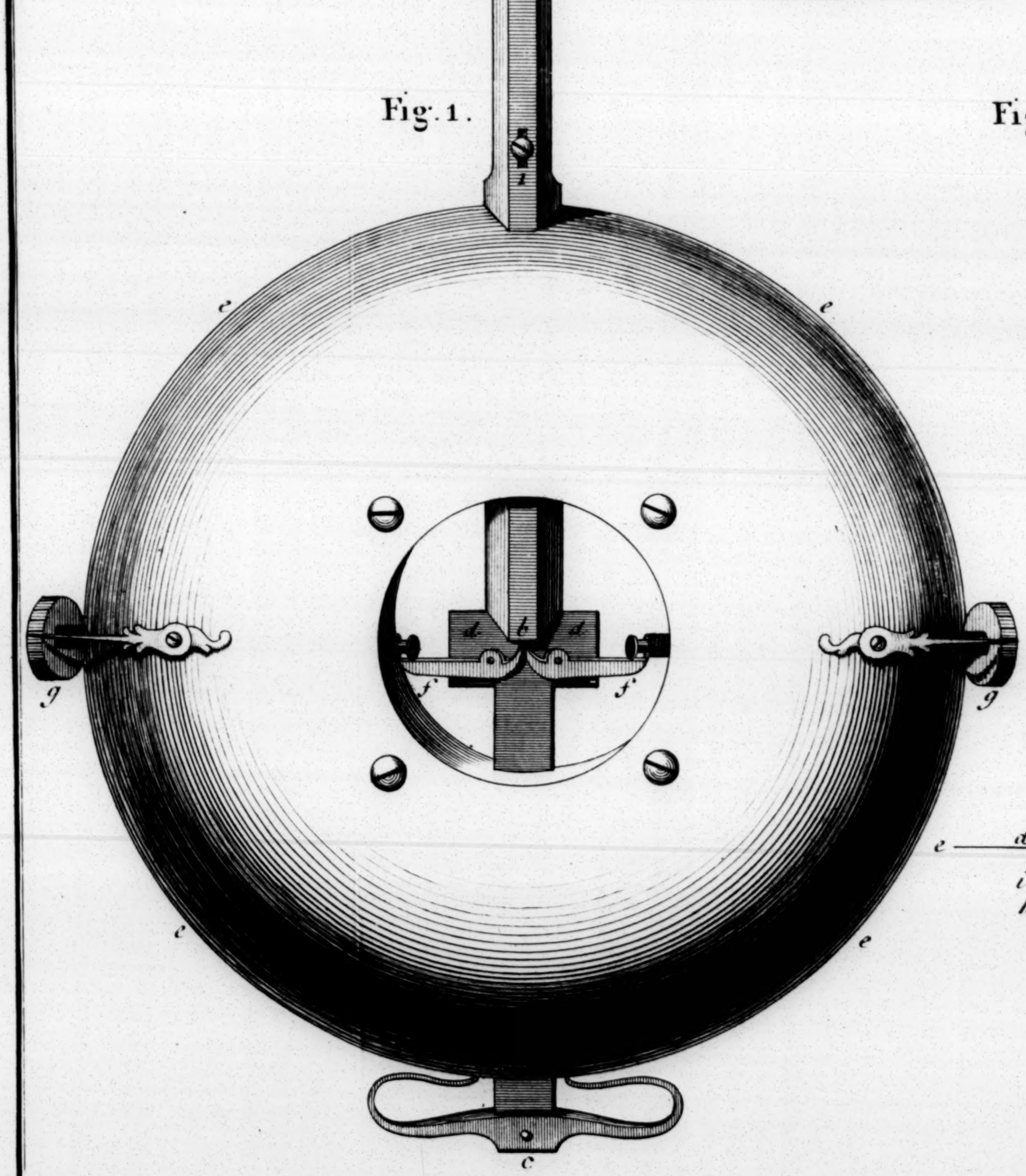

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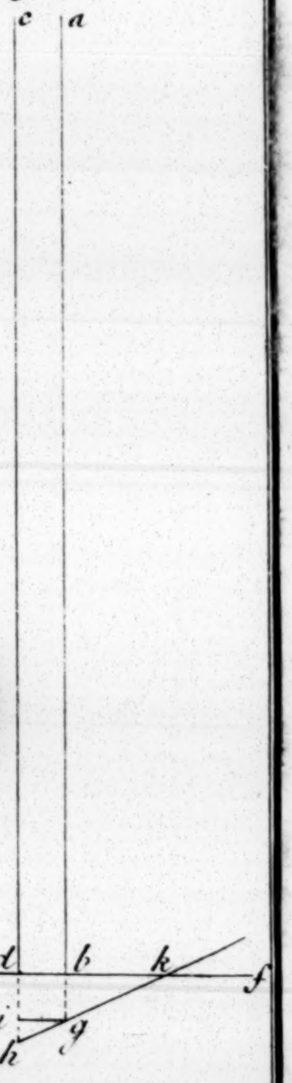
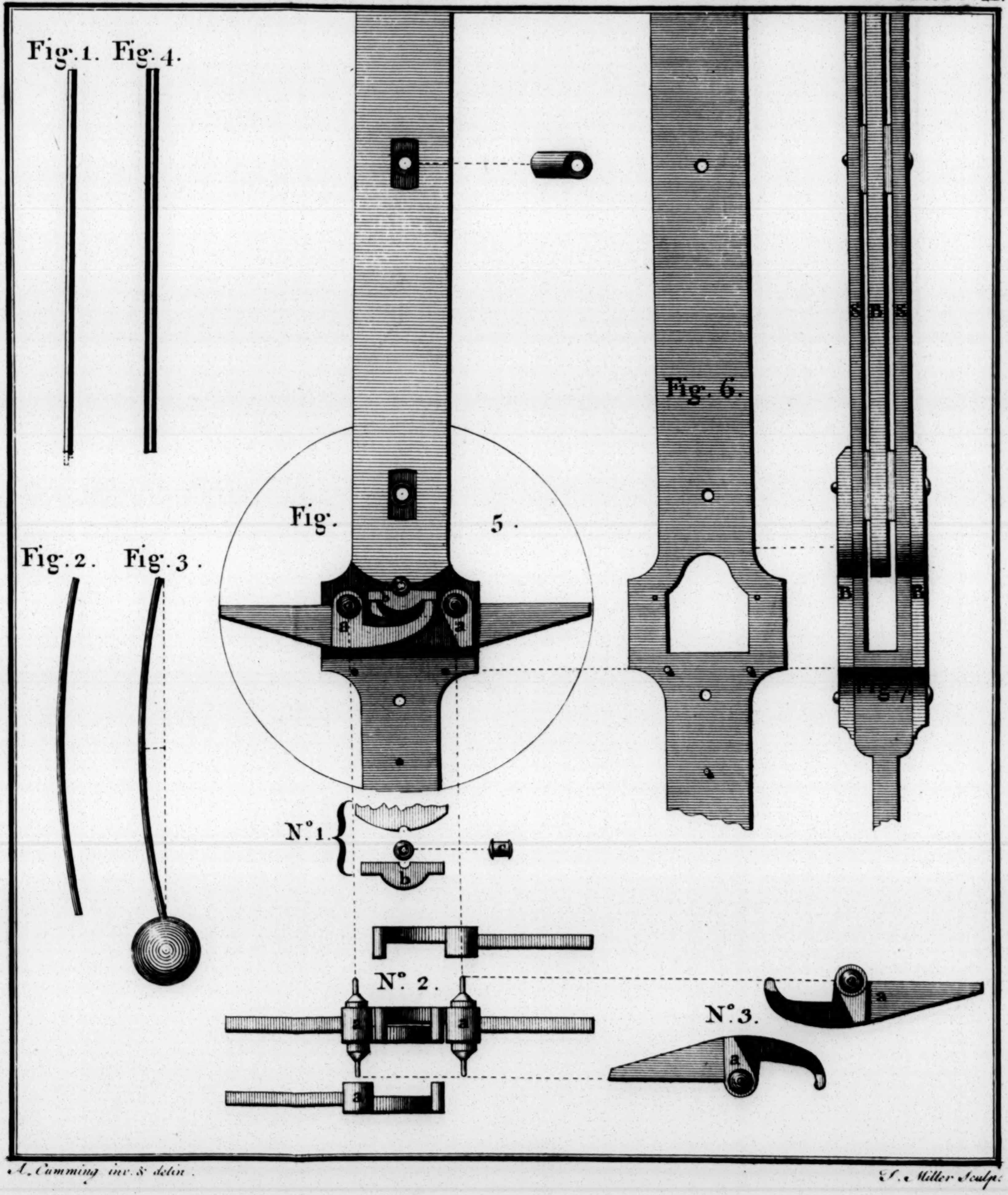


J. Ellicott inv.

J. Miller Sculp.

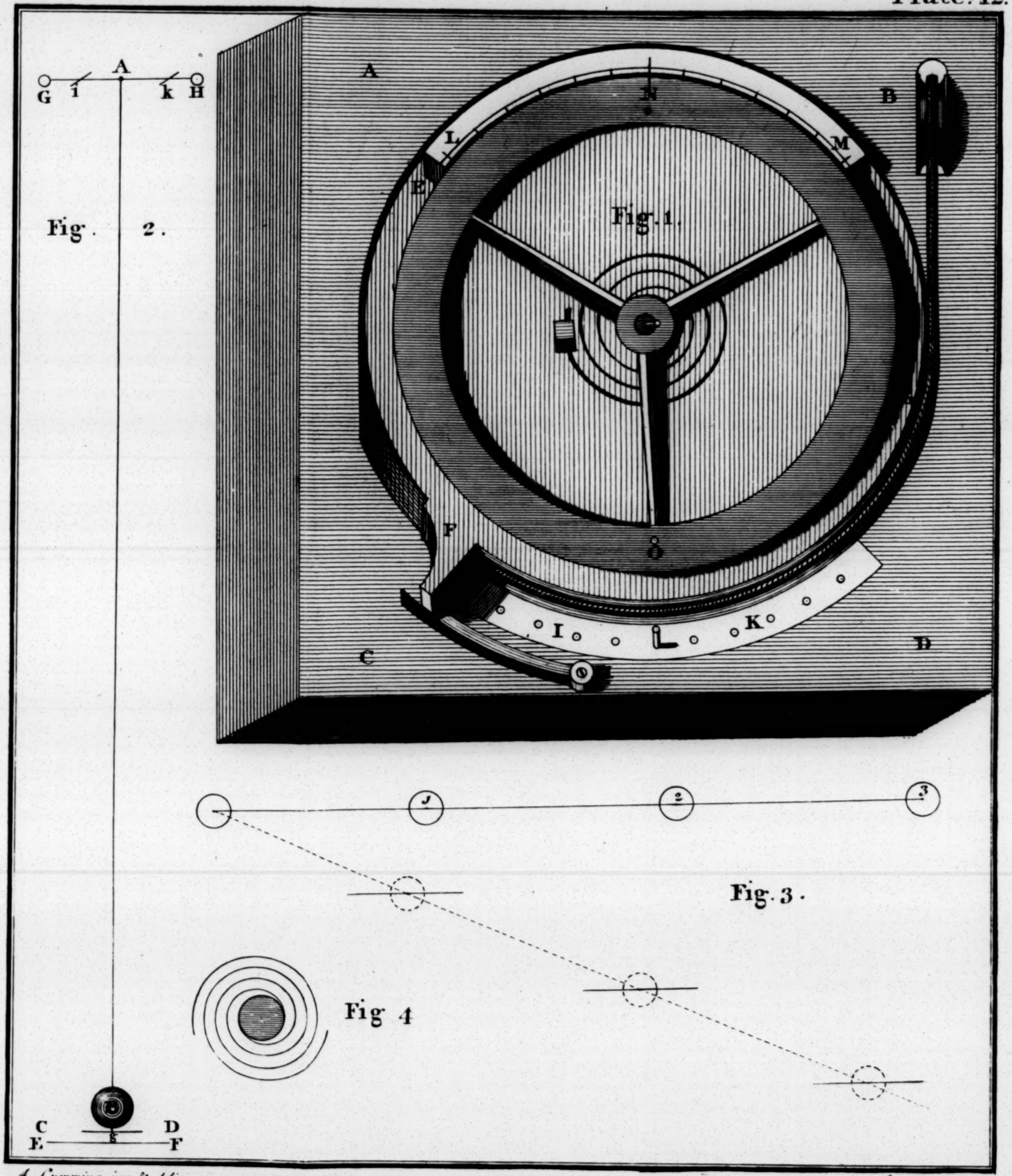
Plate. II.



A. Cumming inv. & delin.

J. Miller Sculp.

Plate. 12.



A. Cumming inv. & delin. *J. Miller Sculp.*

Plate 13

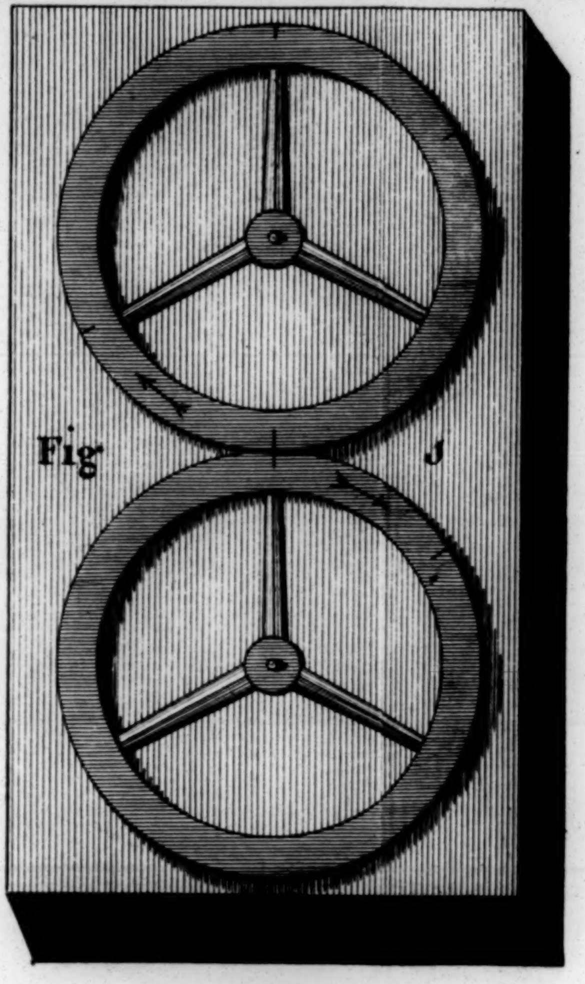


Fig. 1

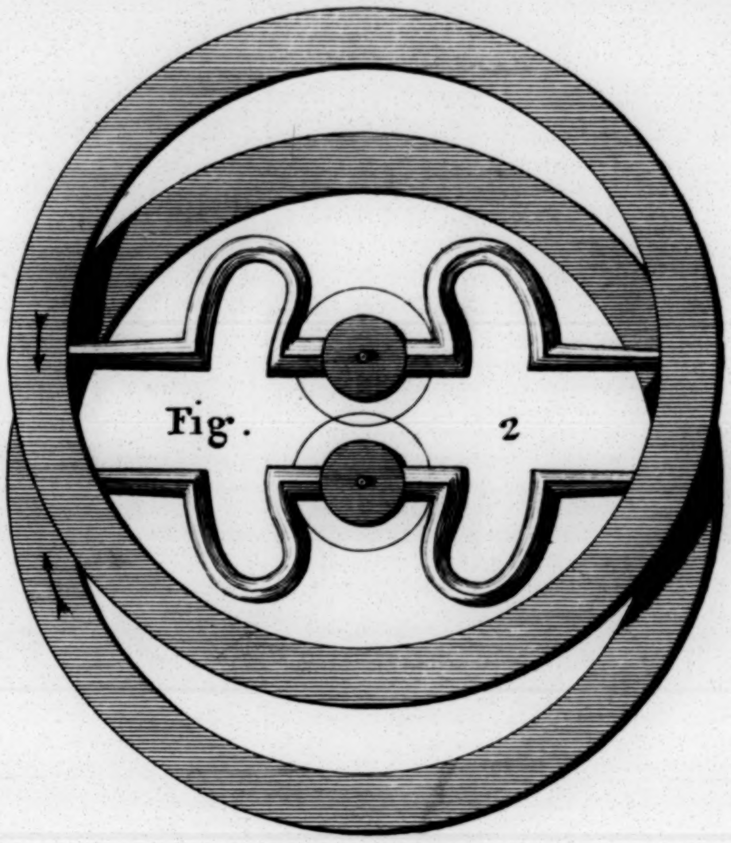


Fig. 2

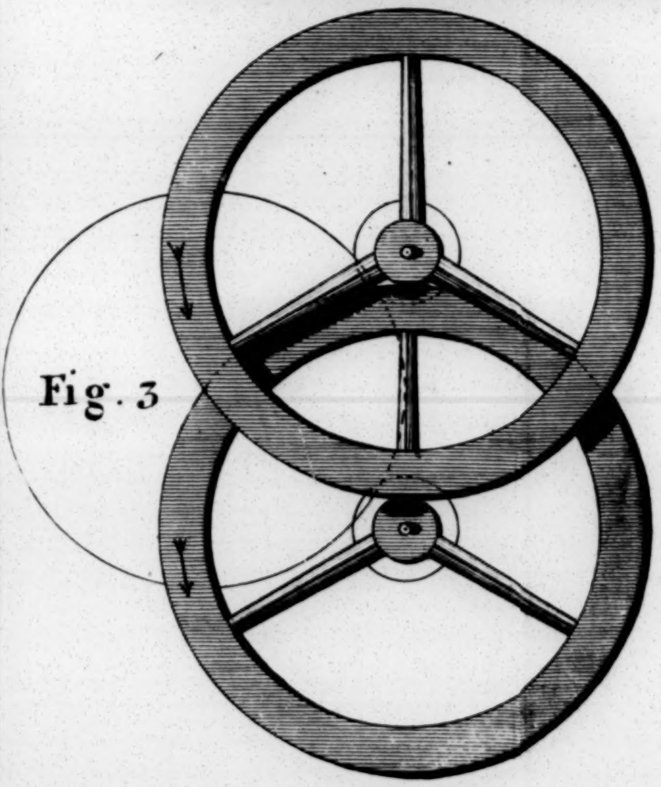


Fig. 3

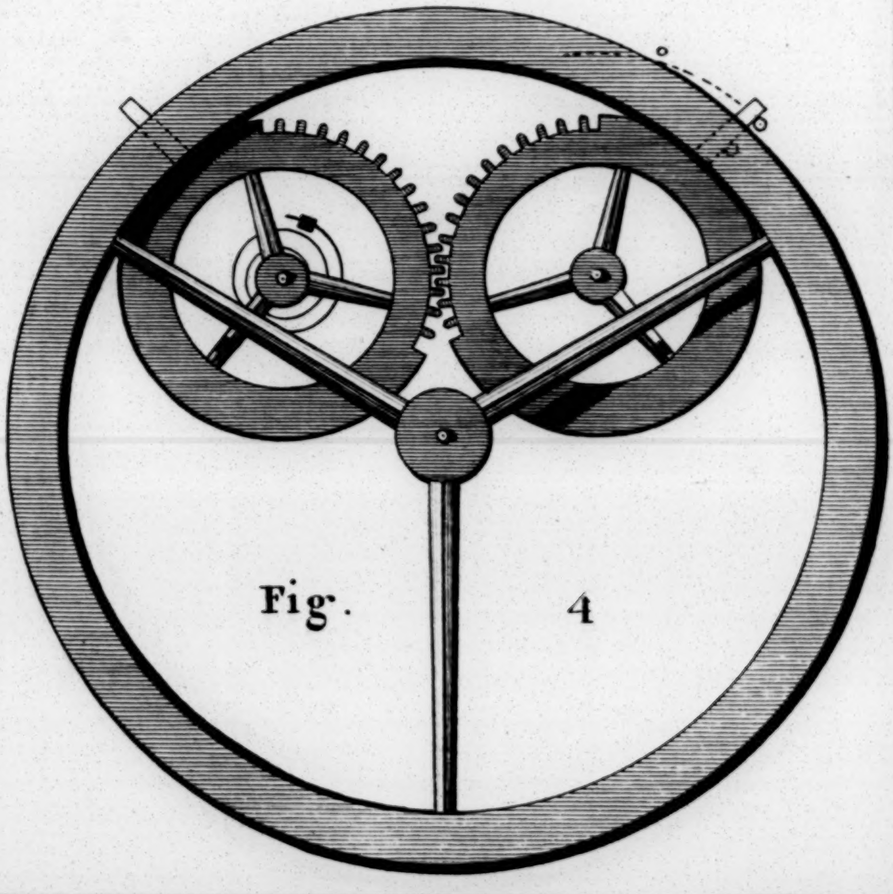
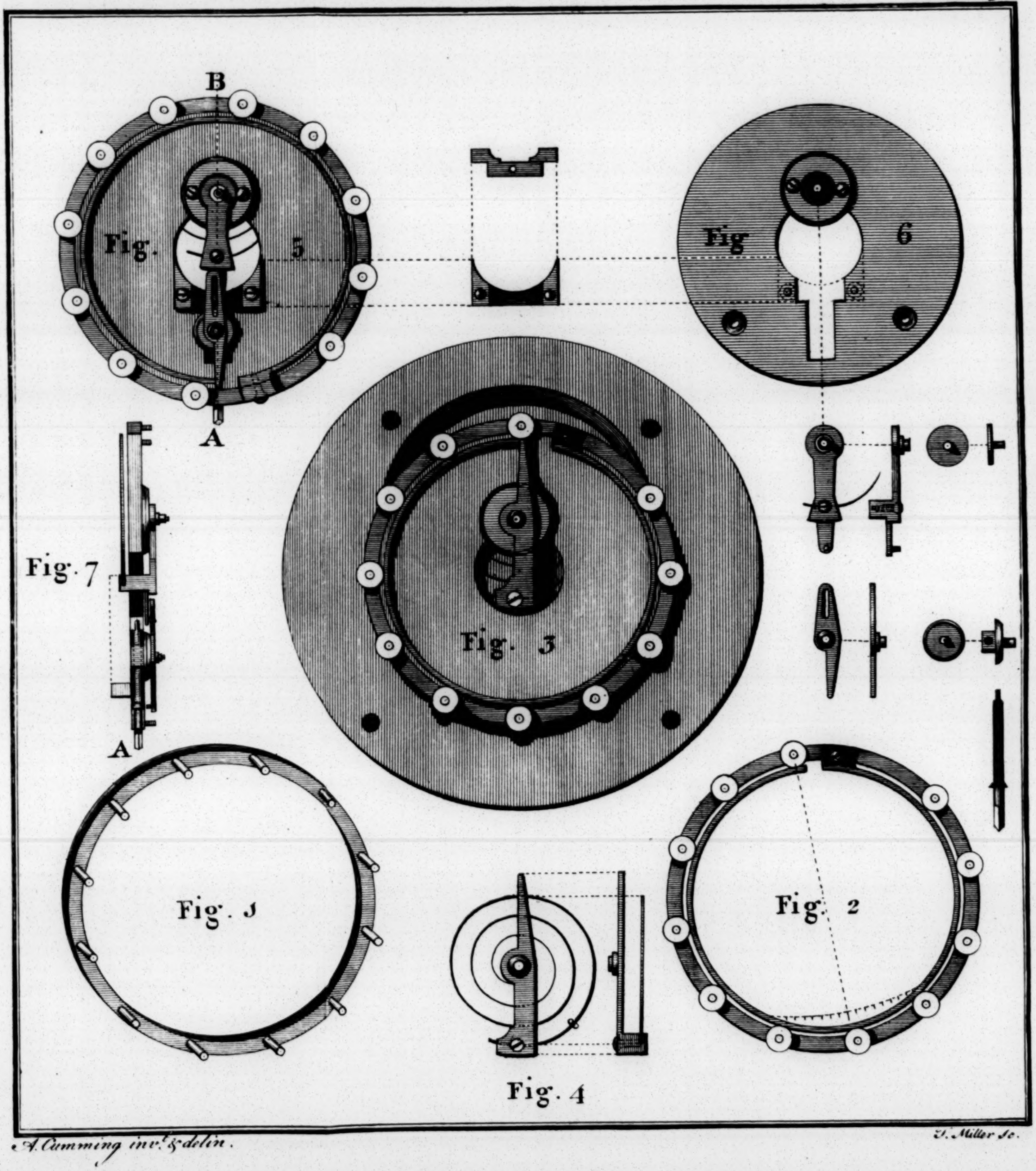


Fig. 4

A. Cumming inv.^{t} & delin. J. Miller Sculp.

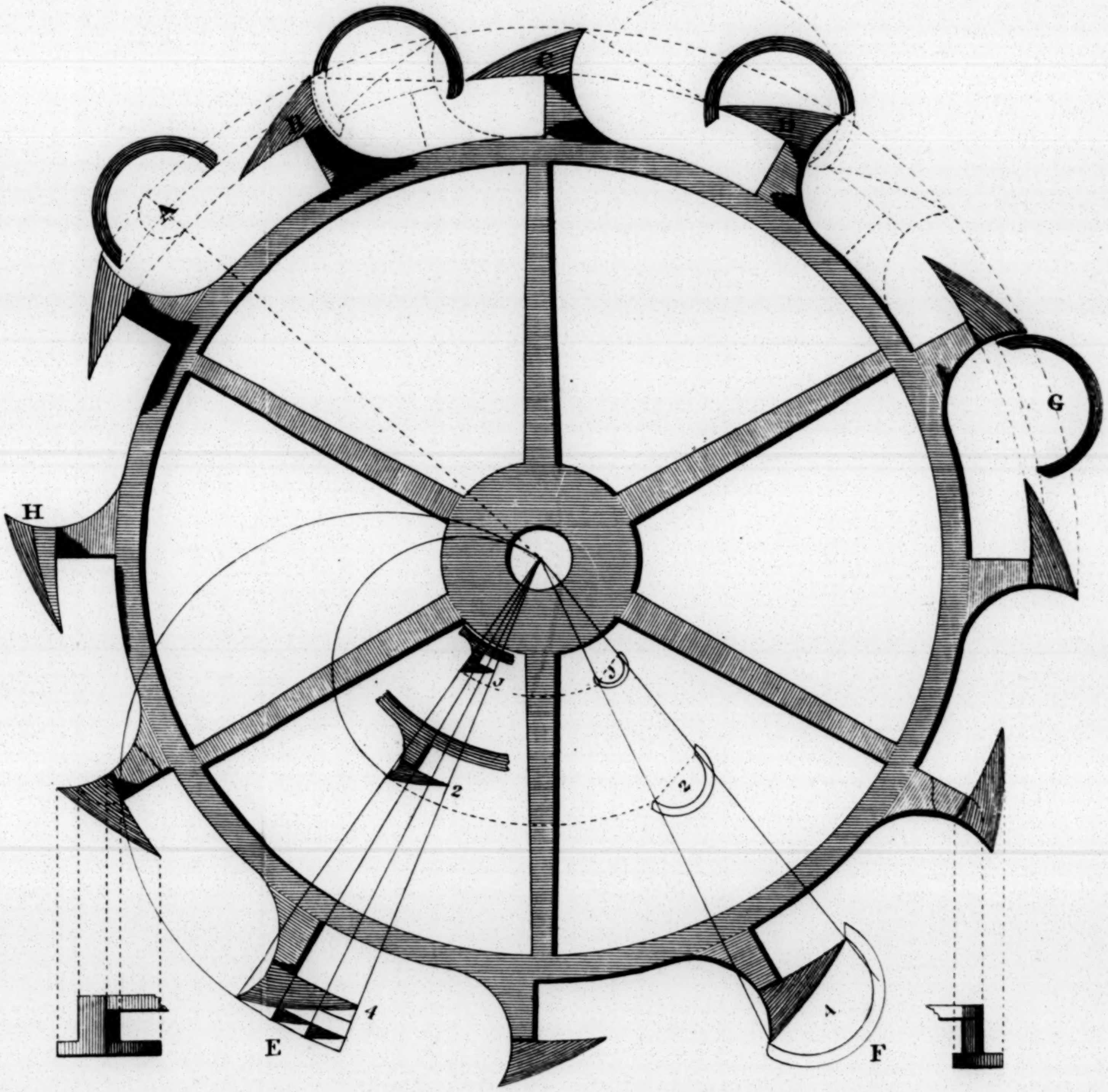
Plate 14



A. Cumming inv.t & delin.

J. Miller sc.

Plate. 15.



A. Cumming inv. & delin

T. Miller Sculp.

Plate. 16.

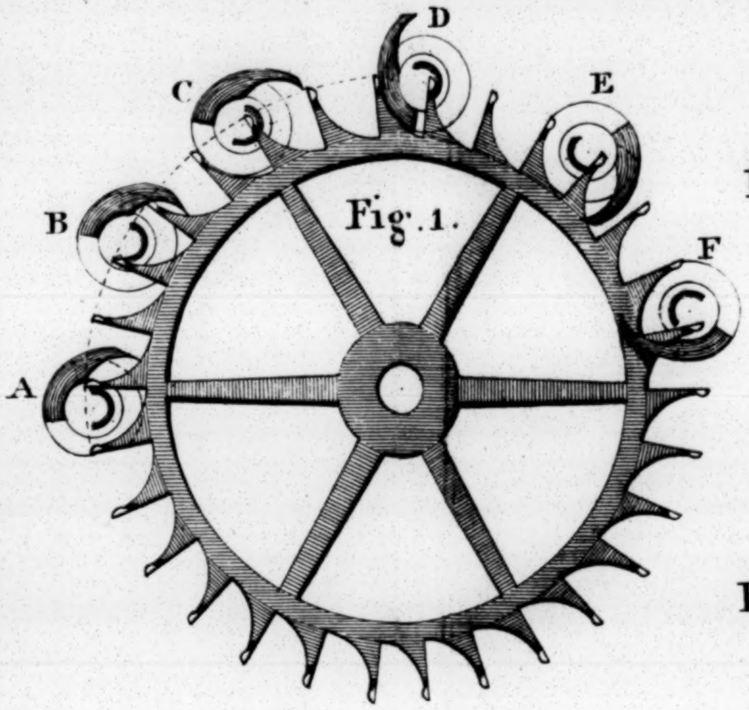


Fig. 1.

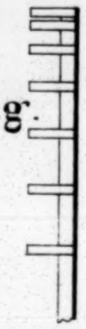


Fig. 2.

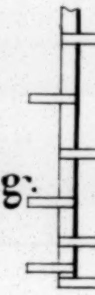


Fig. 3.

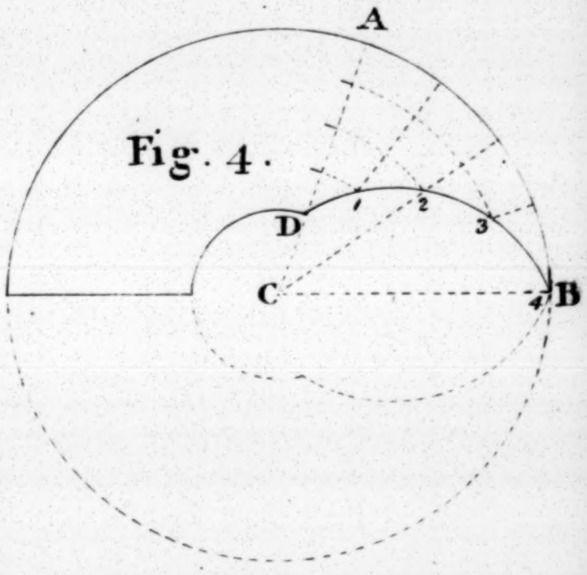


Fig. 4.

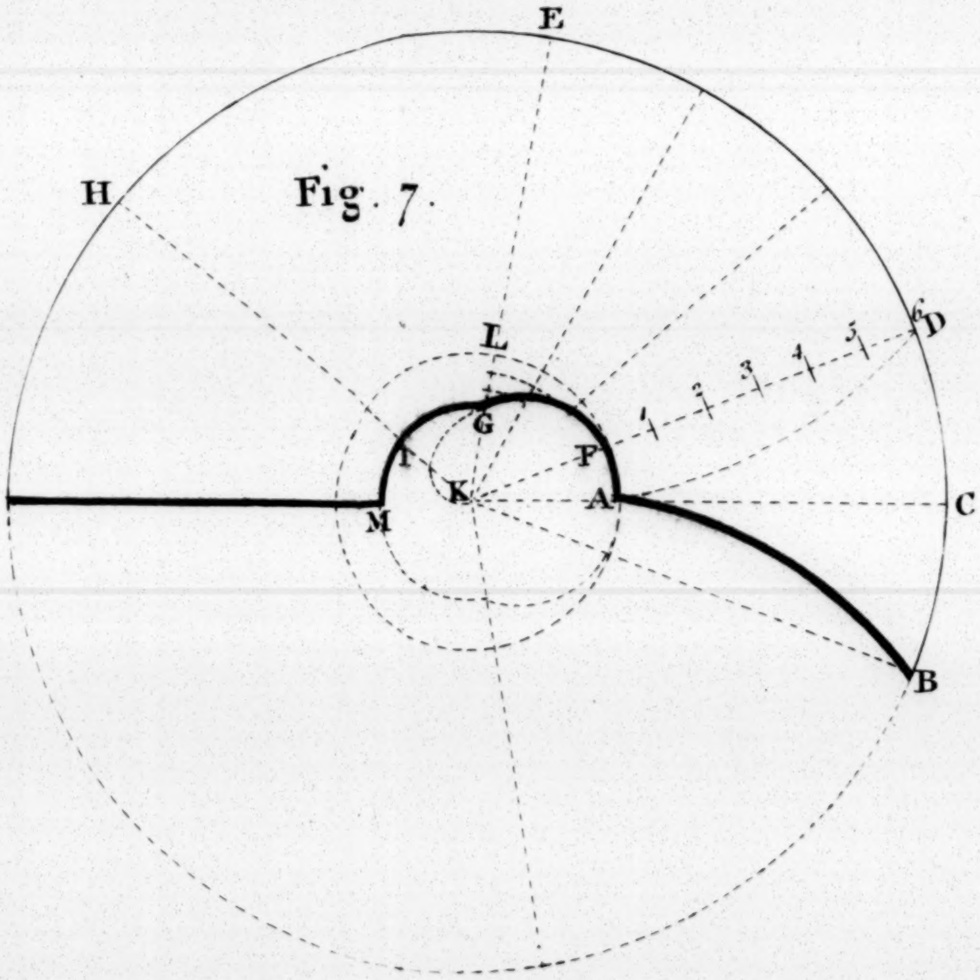


Fig. 7.

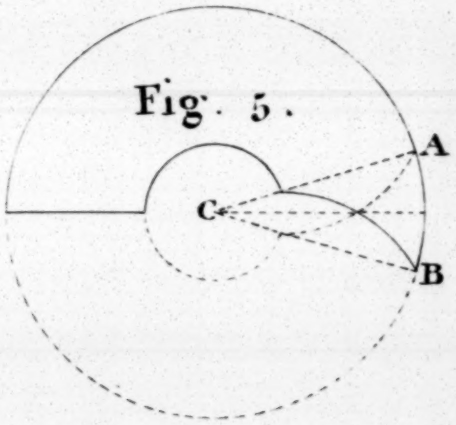


Fig. 5.

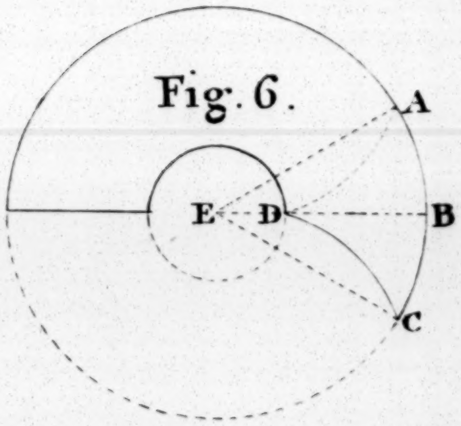


Fig. 6.

A. Cumming inv. & delin.

J. Miller Sculp.